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DEVELOPMENT OF SELF-LUBRICATING AND
NON-ADHERING ELASTOMERIC MATERIALS

Fourth Quarter and Final Report

Prepared Under Navy, Bureau of Naval
Weapons, Contract NOw-60-0123-C

DEVELOPMENT OF SELF-LUBRICATING AND

NON-ADHERING ELASTOMERIC MATERIALS

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Fourth Quarter and Final Summary Report

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United States Rubber Company
Naugatuck Chemical Division
Naugatuck, Connecticut

ABSTRACT

In the development of self-lubricating and non-adhering elastomeric materials, the main property investigated was the surface friction properties of rubber compounds with the object of developing compounds with low starting coefficient of friction values. A simple test apparatus and procedures which measured quantitatively the starting coefficient of friction was developed.

The lowest starting coefficient of friction values which remained constant over the range of applied loads were obtained by modifying a nitrile rubber elastomeric base compound with a fluorocarbon fabric laminate or fluorocarbon chemical treatment of the surface, the Quantum, Inc. "slippery" rubber process. Polysulfide fluorocarbon and silicone rubbers showed low SC_f values which remained fairly constant over the range of applied loads. However, these did not approach the results obtained with fluorocarbon films on elastomeric bases.

Experiments were designed to investigate the mechanism seizure of rubber compounds with metal parts during sustained periods of idleness. Investigation of the effect of contact time under load at 73°F and 50% relative humidity on starting coefficient of friction values for compounds made with nitrile, polyurethane, polysulfide and fluorocarbon rubbers

indicates that the so-called seizure phenomena did not develop. However, by changing the test conditions to 100°F, 100% relative humidity and 96 hours contact time, a definite increase in the starting coefficient of friction values was noted. This increase in SC_f values for elastomeric bases with fluorocarbon films appears to indicate that the so-called "seizure" phenomena is induced by increased humidity and temperature conditions.

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DEVELOPMENT OF SELF-LUBRICATING AND NON-ADHERING ELASTOMERIC MATERIALS

INTRODUCTION

The objective of Contract NOw-60-0123-C was to perform research and development using the contractor's best efforts toward the development of elastomers which, when molded into items for ordnance applications, would have self-lubricating and non-adhering properties. To develop "anti-seizure" or self-lubricating and non-adhering elastomeric compounds, it was necessary to investigate the mechanism of seizure of rubber with metal parts during sustained periods of idleness with the object of developing materials with low static or starting friction and/or breakaway force. Since all frictional force values were converted to coefficient of friction, hereafter in this report, static or starting friction and/or breakaway force will be called starting coefficient of friction or SC_f.

This investigation involved the following phases:

1. A literature search on the friction properties of materials, particularly elastomers, for the purpose of background.
2. Development of a simple test apparatus and procedures which measured quantitatively the starting coefficient of friction.

3. Preparation of experimental, cured elastomeric compounds using commercially or experimentally available raw elastomers containing normal compounding ingredients and suitable testing of these compounds.

4. Investigation of modifying ingredients which have lubricating properties, such as graphite, molybdenum disulfide, teflon, either in the compounds of item three (3) or as films on elastomeric bases and suitable testing of these compounds.

5. Preparation of experimental raw elastomers with intent of finding a type or types better than those commercially available and suitable testing of cured compounds.

6. Investigation of the mechanism of seizure of rubber with metal parts during sustained contact time periods under load.

Other characteristics examined were:

1. Physical properties such as modulus, tensile strength, elongation, hardness, compression set and abrasion resistance.

2. Resistance to temperature, both high and low.

3. Resistance to hydraulic fluids and salt water.

The work presented in this report is the result of efforts by Messrs. A. S. Krivitsky, D. L. Davis, A. V. Perella and W. E. Galwardy.

WORK ACCOMPLISHED

During the first, second and third quarters, the following was accomplished:

1. A simple test apparatus and procedure for measuring quantitatively the starting coefficient of friction of elastomeric materials was developed.
2. An extensive literature search covering the subject of rubber friction was completed.
3. Starting coefficient of friction data were obtained at various load, velocity and contact times under load conditions for a low acrylonitrile content nitrile rubber "O" ring compound. SC_f data reproducibility was also investigated for this compound.
4. Preparation of experimental, cured elastomeric compounds and determination of starting coefficient of friction values and physical properties for these compounds. The compounds tested were made with both commercially available and experimentally prepared rubbers, and contained normal compounding ingredients.
5. Effect of variable contact time under load on the starting coefficient of friction for a polyurethane rubber compound.

6. Preparation of experimental cured elastomeric compounds from commercially available rubbers and containing modifying ingredients which have lubricating properties, such as graphite or silicone grease. Starting coefficient of friction values and physical properties were determined for these compounds.

7. Determination of the starting coefficient of friction of a low acrylonitrile content nitrile rubber compound coated with teflon.

The work during the fourth quarter was directed toward the investigation of the following:

1. Retesting of the starting coefficient of friction of a low acrylonitrile content nitrile rubber compound coated with teflon.

2. Effect of variation in the Shore "A" hardness of cured elastomeric compounds containing normal compounding ingredients on the starting coefficient of friction properties.

3. Evaluation of fabrics made with teflon fiber and blends of teflon and cotton fibers, laminated to a low acrylonitrile content nitrile rubber compound.

4. Evaluation of compounds made with commercially available and experimentally prepared rubbers

containing normal compounding ingredients and treated with Quantum, Inc. "slippery" rubber process.

5. Evaluation of compounds made with commercially available rubbers and modified with lubricating additives.

6. Evaluation of compounds made with commercially available silicone rubbers.

7. Evaluation of compounds made with experimentally prepared polybutadiene and polyurethane rubbers.

8. Investigation of the effect of contact time under load for compounds made with the following rubbers:

   a. low acrylonitrile content nitrile rubber

   b. polysulfide rubber

   c. fluorocarbon rubbers

9. Investigation of the effect of humidity, temperature and contact time under load for a low acrylonitrile content nitrile rubber compound alone and modified as follows:

   a. teflon fabric laminated to contact surface

   b. contact surface treated with Quantum "slippery" rubber process

10. Testing the above compounds for starting coefficient of friction and original physical properties such as modulus, tensile and hardness.

All compounds were formulated and processed using the best recommended procedures provided by the suppliers of the materials.

DISCUSSION

Determination of Starting Coefficient of Friction Data

Using the simple test apparatus and procedures described in the First Quarter report of Contract NOw-60-0123-C, the starting coefficient of friction data shown in this report are obtained by measuring the frictional force or pull at very low speeds or velocities and dividing by the applied load, that is, $SC_f = \frac{FF}{W}$, where "FF" is the pounds pull recorded on the stress - time and autographic chart and "W" is the applied load. Frictional force (FF) is determined as that point on the curve drawn on the stress-time chart where the maximum pull is obtained prior to a decrease in this property indicating sliding or dynamic friction.

Standard of Comparison for Starting Coefficient of Friction Properties

In both the second and third quarter reports of this contract, the SC_f data obtained for the teflon coated low acrylonitrile content nitrile rubber "O" ring compound showed the lowest starting coefficient of friction values which remained constant at the high and low ends of the applied load range. These data were used as the standard of comparison or target level of values which will eventually identify a solution.

In this quarter, the teflon coated nitrile rubber compound test specimens were retested for SC_f values and data are reported in Table VI and Figure 13 of this report. SC_f values ranging from 0.25 at the 20 pound applied load to 0.11 at the 160 pound applied load were obtained.

Starting Coefficient of Friction

Effect of Variation in Compound Hardness

Technical literature on rubber friction contains many references which indicates that the coefficient of friction decreases as the hardness of a rubber compound is increased. Several experiments were designed to investigate the relationship of starting coefficient of friction properties with a variation in compound hardness of five commercially available rubbers. The four different types of rubbers tested and the variations in compound hardness for each type are:

	Type	Variation in Hardness
1.	Low acrylonitrile content nitrile rubber "O" ring compound	68 and 80
2.	Polysulfide rubber	63 and 88
3.	Fluorocarbon rubber	66, 70, 77 and 85
4.	Polyurethane rubber	56, 70, 83 and 96

The SC_f data in Tables I through V which are represented graphically in Figures 1 through 12 show that an increase in the Shore "A" hardness of a rubber compound by increasing the reinforcing pigment loading indicates the following conclusions:

1. For the nitrile and polysulfide rubber compounds, the starting coefficient of friction values for high hardness stocks were lower in the 20 to 60 pound applied load area than in the higher load range.
2. With the 83 and 96 hardness polyurethane rubber compounds, the decrease in starting coefficient of friction was apparent throughout the full range of applied loads tested.
3. Increasing the hardness of the fluorocarbon rubber compounds did not show a decrease in the starting coefficient of friction values at any of the applied load levels tested.
4. Of the four different types of rubber tested in this group, the polysulfide and fluorocarbon rubber compounds gave the lowest and most constant range of SC_f values when tested under increasing load conditions.

Starting Coefficient of Friction

Evaluation of Teflon Fabrics Laminated to a Butadiene-Acrylonitrile Rubber Compound

A possible solution to the problem of developing a self-lubricating and non-adhering elastomeric material would be the bonding of a non-seizing material such as teflon to an elastomeric base. The low acrylonitrile content nitrile rubber compound coated with a teflon emulsion is a good example of this technique. Another method would be to laminate teflon fabrics to the surface of the elastomeric base compound. Four fabrics made with teflon or teflon-cotton fibers and constructed as described below were laminated to a low acrylonitrile content nitrile rubber "O" ring compound and tested for starting coefficient of friction properties. The fabrics tested were as follows:

1. Circular knit fabric made of a 50/50 blend by weight of cotton and teflon fibers (5.5 singles yarn).
2. Circular knit fabric made of 800/120 teflon textured fiber.
3. Double woven fabric oontaining "teflon" fiber on one surface and cotton on the other side.
4. "Teflon" woven fabric with one surface napped or brushed.

All fabrics were mechanically bonded under pressure to the nitrile rubber compound shown in Table VII. The SC_f data of Table VII and represented graphically in Figures 14 through 18 indicate the following conclusions:

1. Manual adhesion tests on the various "teflon" fabrics laminated and mechanically bonded to the elastomeric base indicated excellent adhesion, particularly with the fabric which is napped on one side.
2. Very low starting coefficient of friction values which remained constant at both ends of the applied load range were obtained with all four fabrics compared to the elastomeric base without fabric. The lowest SC_f values were obtained with the straight "teflon" fiber on one side and either a cotton or napped (brushed) surface on the other side.

Starting Coefficient of Friction Evaluation of Various Rubber Compounds Treated with "Slippery" Rubber Process

During the past year, Quantum, Inc. or Wallingford, Connecticut, a research and development organization, announced the development of a process which makes rubber "slippery" without affecting its elasticity and other inherent properties. As described in a publicity press release, the Quantum process

makes the "slippery" or low friction surface rubber by graft polymerizing chemically active monomers or oligomers to the cured elastomer surface. The graft polymer is then hydrolyzed to the corresponding acid form and fluorinated, the hydrogen atoms in the surface being replaced by fluorine atoms. The result is a surface with low dipole force, thus a low level of attraction contacting surface.

Twenty-one (21) cured friction test specimens prepared from compounds representing five (5) commercially available rubbers and two (2) experimentally prepared copolymers were submitted to Quantum, Inc. for contact surface treatment by their process. Compounds made from the following rubbers were submitted:

1. Vibrathane 5003 - a polyurethane rubber
2. Thiokol ST - a polysulfide rubber
3. PARACRIL 18-80 - a low acrylonitrile content, butadiene-acrylonitrile rubber
4. NAUGAPOL 1015 - a low styrene content, butadiene-styrene rubber
5. NAUGATUCK Cis - 4 - Polybutadiene - a stereospecific polybutadiene rubber
6. Ethylene-propylene EP-931 - Experimental stereoblock ethylene-propylene copolymer. Planned configuration
7. Ethylene-Propylene J-9028-A - Experimental stereoregular ethylene-propylene copolymer - Random configuration.

Compound formulations and SC_f data for the rubbers tested are shown in Table VIII and are represented graphically in Figures 19 through 28. The polyurethane and polysulfide rubber specimens were not tested due to a very bad softening effect apparently caused by the treatment.

The following conclusions can be made from the SC_f data in Table VIII:

1. The Quantum "slippery" rubber process considerably reduced the starting coefficient of friction values of all rubbers tested. In addition, the level of SC_f values over the range of applied loads tested appears to remain constant.
2. SC_f values approaching those of the teflon emulsion coated nitrile rubber were obtained with the butadiene-acrylonitrile, butadiene-styrene and polybutadiene rubber compounds treated with the "slippery" rubber process.

Starting Coefficient of Friction Evaluation of Experimental Cured Elastomeric Compounds Modified with Lubricants

An important phase of this contract is the preparation and testing of the starting coefficient of friction and physical properties of experimental cured elastomeric compounds representing various raw elastomers containing modifying ingredients

which have lubricating properties. Four (4) different commercial raw elastomers were compounded with normal compounding ingredients plus the following lubricating additives:

a. Fluorocarbon fiber floc

b. Fluorocarbon resins

c. Fluorocarbon wax

d. Fluorocarbon oil

e. Fluorocarbon telomers

f. Fluorocarbon solvent dispersions

g. Molybdenum disulfide

h. Lithium stearate modified paraffin wax

i. Extreme pressure lubricant

j. Graphite

Starting coefficient of friction values at various applied loads and original physical properties were obtained for these compounds and are reported in Tables IX through XVIII. These data are represented graphically in Figures 29 through 62 and indicate the following conclusions:

1. The starting coefficient of friction values at the low applied load levels (20 to 60 pounds) of butadiene-acrylonitrile or fluorocarbon rubbers are reduced slightly by the addition of the following materials:

a. Fluorocarbon fiber floc, resins, wax and oil

b. 20 parts per hundred of rubber of molybdenum disulfide

c. Extreme pressure lubricant Flexamet PCM 1278. This material contains molybdenum disulfide as an additive.

d. 20 parts of rubber grade graphite

2. Lithium stearate modified paraffin waxes C-29-BP, C-29-BQ and C-29-BS added to a butadiene-acrylonitrile rubber compound at a 2.0 part per hundred of rubber level appear to reduce the SC_f values at the low applied load level. Wax C-29-BQ had the greatest effect on this property when added to either nitrile or fluorocarbon rubber compounds.

3. Low molecular weight waxy telomers of teflon (TLT-111) and a dispersion of the telomer in a chlorinated solvent (Vydox A) do not affect the starting coefficient of friction properties of butadiene-acrylonitrile rubber or polysulfide rubber compounds.

Starting Coefficient of Friction

Evaluation of Experimental Cured Elastomeric Compounds

The major portion of this contract involves the preparation and testing of the starting coefficient of friction and physical properties of experimental cured elastomeric compounds made with

commercially available and experimentally prepared rubbers. In addition to the commercial and experimental rubbers previously tested and reported in the second and third quarter reports, the following rubbers were compounded with normal compounding ingredients and evaluated for original physical properties and starting coefficient of friction at various applied loads:

1. Two fully compounded silicone rubbers
2. One experimental polybutadiene rubber prepared by emulsion polymerization
3. Five experimental polyurethane of various chemical modifications, with and without silicone oil - molybdenum disulfide lubricants

SC_f data and original physical properties are reported in Tables XIX through XXI. Graphic representation of SC_f data are shown in Figures 63 through 71. The following conclusions can be made from these data:

1. Silicone rubber compounds, Silastic LS-53 and Silastic 82 gave starting coefficient of friction values in the area of the fluorocarbon and polysulfide rubbers.
2. Emulsion polymerized polybutadiene showed SC_f data essentially equal to stereoregular polymerized polybutadiene except for a slightly lower level of values at the low applied loads.

3. The starting coefficient of friction values for the five experimental polyurethane rubber compounds in most cases were higher than the standard polyurethane rubber, Vibrathane 5003, compound.

Starting Coefficient of Friction

Effect of Contact Time Under Load

Previous experiments by the Navy at the David Taylor Model Basin and various reports in the literature on friction indicate that static or starting friction increases with contact time under load. In the Second Quarter and Third Quarter Report of Contract NOw-60-0123-C, data are reported for experiments investigating the above property using test specimens made with a low acrylonitrile content (PARACRIL 18-80) nitrile rubber compounded in a typical "O" ring formulation and a typical 70 hardness polyurethane compound. These data did not show an increase in the starting coefficient of friction with increasing contact time under load. New experiments were designed to investigate the so-called seizure property on compounds made with the following various types of rubber:

1. A low acrylonitrile content butadiene-acrylonitrile rubber "O" ring compound
2. A polysulfide rubber compound
3. A polysulfide rubber compound with graphite lubricant
4. Two fluorocarbon rubber compounds

Compounds and data are tabulated in Tables XXII through XXVI. Tests conducted with test specimens under load for various time cycles ranging from two (2) hours to forty-eight (48) hours showed the following:

1. With the butadiene-acrylonitrile and polysulfide rubber compounds, no major change in starting coefficient of friction values was noted at any of the contact time cycles.
2. With the two fluorocarbon rubber compounds, there appeared to be an increase in SC_f value which leveled off after 2 hours contact time.

Starting Coefficient of Friction

Effect of Contact Time Under Load at

Certain Humidity and Temperature Conditions

Previous experiments designed to reproduce the so-called seizure phenomena of the elastomeric materials by testing the rubber compound test specimens for starting coefficient of friction after conditioning under load for various time cycles were unsuccessful, with the exception of the two fluorocarbon compounds tested in the fourth quarter. In some private work, Naugatuck Chemical undertook a study of the relative corrosion effects of 1020 steel of nitrile rubber compounds and the various ingredients used in seal compounds

under conditions of high humidity and temperature. The accelerated corrosion test developed to simulate the conditions of high humidity and temperature often encountered in the field consists of a three piece sandwich, made with two 1020 steel plates and a rubber test piece compressed between them. The sandwich is placed in a chamber for 96 hours at 100% relative humidity and 100°F. At the end of the test period, the sandwich units are disassembled, cleaned, and rubbed lightly with crocus cloth to remove stains and adhered rubber particles. Prior to the disassembling of the sandwich units, it was noted that there was a tendency for the rubber test pieces to stick to the metal panels. Based on this observation, several experiments were designed to investigate the effect of humidity and temperature on the starting coefficient of various test specimens under load for various contact time cycles with steel plates used in the friction studies for this oontract. The following test specimens were investigated in this study:

1. A low acrylonitrile content butadiene-acrylonitrile rubber "O" ring compound
2. The compound in Item 1 treated with the Quantum "slippery" rubber process
3. Teflon woven fabric with the napped surface laminated and mechanically bonded to the compound in Item 1.

Compounds, test conditions and data are reported in Tables XXVII through XXIX.

This study resulted in the following conclusions:

1. A definite increase in the starting coefficient of friction values was noted when the nitrile rubber "O" ring test pieces were conditioned at 100% relative humidity and 100°F for 96 hours contact time as compared to test specimens conditioned for 96 hours at room temperature (73°F) and normal room humidity (50). Forty-eight (48) hour contact time tests made under the high humidity conditions described above did not show an increase in SC_f values. The increase in SC_f values appears to indicate that the so-called "seizure" phenomena was induced by the presence of humidity and increased temperatures.

2. An increase in the starting coefficient of friction value from the low SC_f value obtained in the original tests was noted when the Quantum "slippery" process, treated nitrile rubber "O" ring compound test specimens were tested. Similar results were obtained with the nitrile rubber "O" ring compound to which a "teflon" fabric was laminated.

3. Varying degrees of edge and contact corrosion were

noted with the test specimens which were conditioned at 100% relative humidity and 100°F for 96 hours. The least degree of metal corrosion was obtained with the "teflon" fabric specimens, whereas, the Quantum "slippery" rubber process treated specimens showed the highest amount.

Final Summary Report

Introduction

During the period from June 1, 1960 through July 15, 1961, the contractor used its best efforts to perform research and development of elastomeric materials, which when molded into items for ordnance applications, shall have self-lubricating and non-adhering properties. In the development of anti-seizure or self-lubricating and non-adhering elastomeric compound, the main property investigated was the surface friction properties of rubber compounds, with the object of developing compounds with low static or starting friction and/or break-away force. Since all frictional force values were converted to ceefficient of friction, static or starting friction was called starting coefficient of friction or SC_f.

This investigation involved the following phases:

1. A literature search on the friction properties of materials, particularly elastomers, for the purpose of background.
2. Development of a simple test apparatus and procedures which measure quantitatively the starting coefficient of friction.
3. Preparation of experimental, cured elastomeric compounds using commercially or experimentally

available raw elastomers containing normal compounding ingredients and suitable testing of these compounds.

4. Investigation of modifying ingredients which have lubricating properties, such as graphite, molybdenum disulfide, teflon, either in the compounds of item three (3) or as films on elastomeric bases and suitable testing of these compounds.

5. Preparation of experimental raw elastomers with intent of finding a type or types better than those commercially available and suitable testing of cured compounds.

6. Investigation of the mechanism of seizure of rubber with metal parts during sustained contact time periods under load.

Other characteristics examined were the original or unaged physical properties, such as modulus, tensile, elongation and hardness.

Work Accomplished and Discussion

1. Literature Search - An extensive literature search covering the subject of rubber friction was completed. Concise resumes of the various articles located were reported in the first and second quarterly reports.

2. A simple test apparatus and procedure for measuring quantitatively the starting coefficient of friction of elastomeric materials was developed and reported in the first quarter report.

3. Starting coefficient of friction data were obtained at various load and velocity conditions for a low acrylonitrile content nitrile rubber "O" ring compound. SC_f data reproducibility was also investigated for this compound. These data show the starting coefficient of friction to decrease as the load increases with a leveling of the curve at about 140 pounds applied load. This curve appears to agree with the theoretical curve reported in the literature.

   Experiments designed to investigate the effect of velocity on starting coefficient of friction show the SC_f values to increase as the velocity is increased to 0.15 inches per minute. At this point, SC_f values appear to level off. A velocity of 0.30 inches per minute or full speed of the test apparatus was standardized as the velocity for all tests.

   Starting coefficient of friction tests made over a period of three (3) months using a constant load and constant velocity show good reproducibility.

4. Starting coefficient values ranging from 0.25 at the 70 pound level to 0.11 at the 160 pound level were obtained with teflon emulsion coated nitrile rubber "O" ring compound test specimens. These data were used as the standard or comparison throughout the period of contract.

5. Experimental cured elastomeric 60 - 70 Shore "A" hardness compounds representing thirty-two (32) commercially or experimentally available raw elastomers containing normal compounding ingredients were prepared and tested for starting coefficient of friction and original physical properties. Of the thirty-two (32) rubbers evaluated, the lowest starting coefficient of friction values which remained fairly constant over the range of applied loads were obtained with compounds made from the following:

   a. Polysulfide rubber - Thiokol ST

   b. Fluorocarbon rubbers - Viton A, Kel F Elastomer 3700, Fluorel 2141

   c. Silicone rubbers - Silastic LS-53 and Silastic 82

   d. All other rubbers tested showed high SC_f values at both ends of the applied load scale.

   However, the above rubbers did not approach the SC_f values and constant level of the values under various applied loads obtained with a teflon emulsion coated nitrile rubber "O" ring compound.

Other conclusions which can be made from the data obtained are:

1. SC_f values do not vary with the acrylonitrile content of the nitrile rubber. Modification of the rubber with polyvinyl chloride tends to increase the SC_f values.

2. Although butadiene-styrene copolymers in general do not show SC_f values much different from other high level SC_f polymers, the low styrene content rubbers such as SBR 1015 appear to show a tendency towards lower SC_f values.

3. Variation in polymer structure within a given copolymer such as the ethylene-propylene, butyl and polyurethane rubbers do not appear to change the SC_f properties of the particular rubber.

4. With the exception of the fluorocarbon rubber compounds, increasing the hardness appears to reduce the SC_f values only in the 20 to 60 pound applied load area.

6. Another important phase of this contract was the preparation and testing of the starting coefficient of friction and physical properties of experimental cured elastomeric compounds representing various elastomers with modifiers

which have lubricating properties either as a compounding ingredient or as films on elastomeric bases. Six (6) different types of commercial raw elastomers were compounded with normal compounding ingredients plus various lubricating additives such as graphite, silicone grease or molybdenum disulfide. Other additives tested were fluorocarbon fiber flocs, waxes, oils, telomers, and resins, extreme pressure lubricants, and lithium stearate modified paraffin waxes.

In addition, the surface of several cured rubber compounds were modified by the techniques listed below and tested for starting coefficient of friction:

a. Teflon fabrics laminated and mechanically bonded to a nitrile rubber "O" ring compound.

b. Quantum "slippery" rubber treatment on five (5) commercially available and two experimentally prepared rubbers.

The various modifications made, either as compounding ingredients or films on elastomeric bases, showed the following:

1. The lowest starting coefficient of friction which remained constant over the range of applied loads was obtained with the nitrile rubber "O" ring

compound to which was laminated a teflon fiber with a napped surface on one side. The SC_f values obtained with this construction were the lowest obtained during the period of this contract. Adhesion of the fabric to the rubber compound appeared to satisfactory.

2. The Quantum "slippery" rubber process considerably reduced the SC_f values of compounds made with the following rubbers:

   a. low acrylonitrile content butadiene-acrylonitrile rubber

   b. low styrene content butadiene content butadiene-styrene rubber

   c. polybutadiene rubber

   d. ethylene-propylene rubbers

   In addition, the level of SC_f values appear to remain constant over the range of applied loads tested. SC_f values approaching those of the teflon emulsion coated nitrile rubber were obtained with butadiene-acrylonitrile, butadiene-styrene and polybutadiene compounds treatea with the "slippery" rubber process.

3. In general, the addition of various lubricant modifiers to various rubber compounds as a compounding ingredient was not as effective as the teflon fabric lamination or "slippery" rubber techniques. Slight reductions of SC_f values in the low applied load ranges was obtained with most of the additives tested. Twenty (20) parts of rubber graphite per hundred of rubber added to a nitrile or polysulfide rubber compound appeared to have some value in reducing the SC_f values over the complete range of applied load.

7. Several experiments were designed to investigate the mechanism of seizure of rubber compounds with metal parts during sustained contact time periods under load. Data obtained showed the following results:

   a. With the exception of two (2) fluorocarbon compounds, no major change of starting coefficient of values after sustained contact time periods under load was noted for the nitrile, polysulfide and polyurethane rubber compounds tested.

b. Increases in SC_f values were particularly noted when various test specimens were conditioned at 100% relative humidity, 100°F and 20 pounds load for 96 hours. Various degrees of edge and contact corrosion of the metal plates was also noted. The so-called "seizure" phenomena appears to be induced by humidity conditions.

APPENDIX

TABLE I

Starting Coefficient of Friction

Evaluation of Butadiene-Acrylonitrile Rubber

Varying Hardness Compounds

NOw-60-0123-C	3-C	35-CL
PARACRIL 18-80	100.0	100.0
Zinc Oxide	10.0	10.0
AMINOX	2.0	2.0
Wyex Carbon Black	25.0	25.0
Pelletex Carbon Black	75.0	100.0
Paraplex G-25	10.0	10.0
Plasticizer SC	7.5	7.5
TP-95 Plasticizer	7.5	7.5
TUEX	1.5	1.5
Tetrone A	1.5	1.5
	240.0	265.0

Cure - 30 minutes at 310°F

Test Velocity - 0.30 inches/minute

Applied Load - Pounds	FF	SC_f	FF	SC_f
20	42	2.10	26	1.30
40	62	1.55	49	1.23
60	72	1.20	64	1.07
80	85	1.06	73	0.91
100	98	0.98	88	0.88
120	95	0.79	91	0.76
140	107	0.76	100	0.71
160	113	0.71	110	0.69

Original Physical Properties - Cure 30 minutes at 310°F

Modulus at 100%, psi	560	1160
Tensile, psi	1840	1750
Elongation, %	300	130
Shore "A" Hardness	68	80

FF = Frictional Force
SC_f = Starting Coefficient of Friction

Figure 1

Starting Coefficient of Friction - Evaluation of

Butadiene - Acrylonitrile Rubber - Varying Hardness Compounds

Polymer - PARACRIL 18-80

Compound - NOw-60-0123-C-3-C

Velocity - 0.30 inches/minute

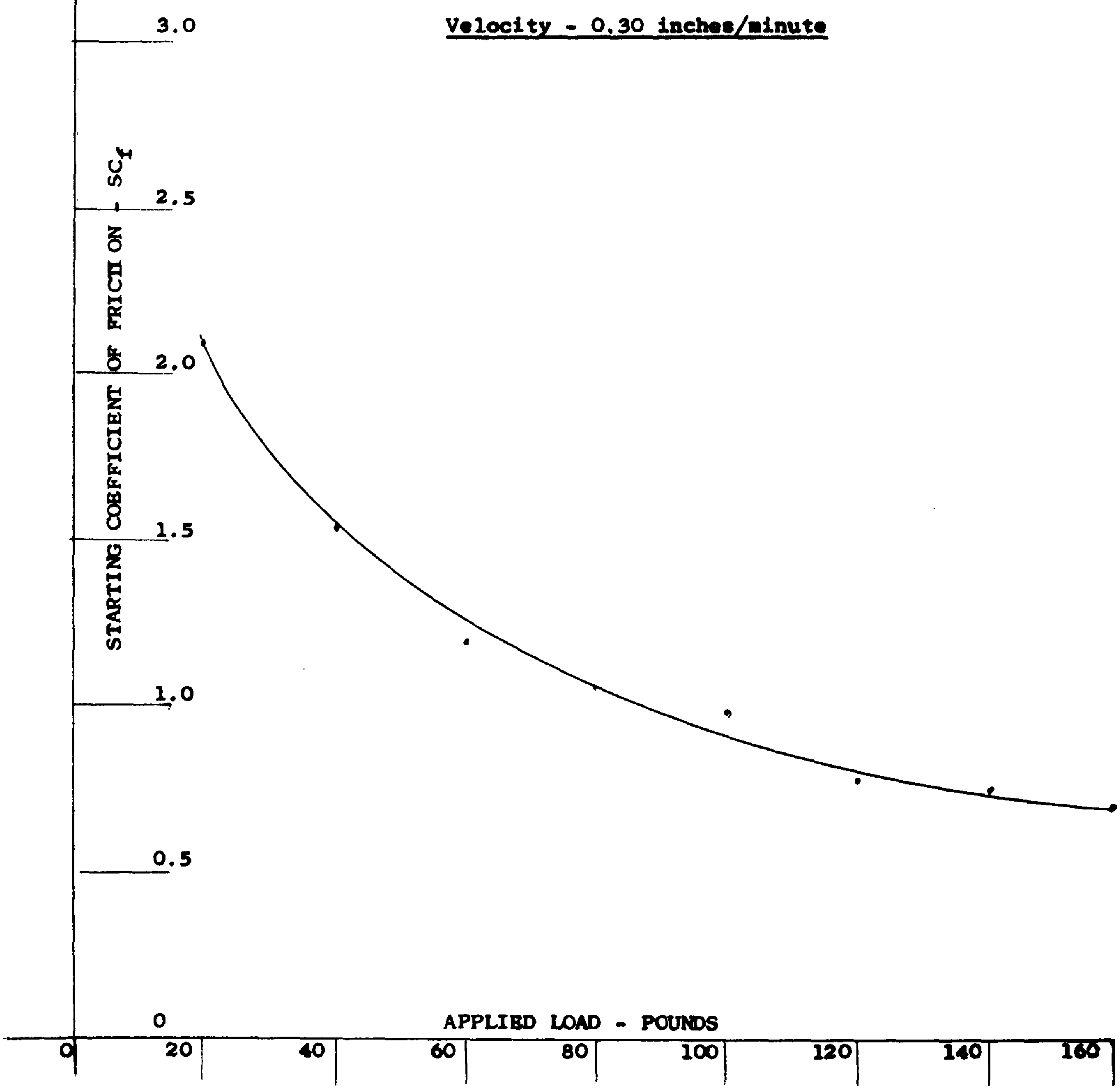


Figure 2

Starting Coefficient of Friction - Evaluation of

Butadiene - Acrylonitrile Rubber - Varying Hardness Compounds

Polymer - PARACRIL 18-80

Compound - NOw-60-0123-C-35-CL

Velocity - 0.30 inches/minute

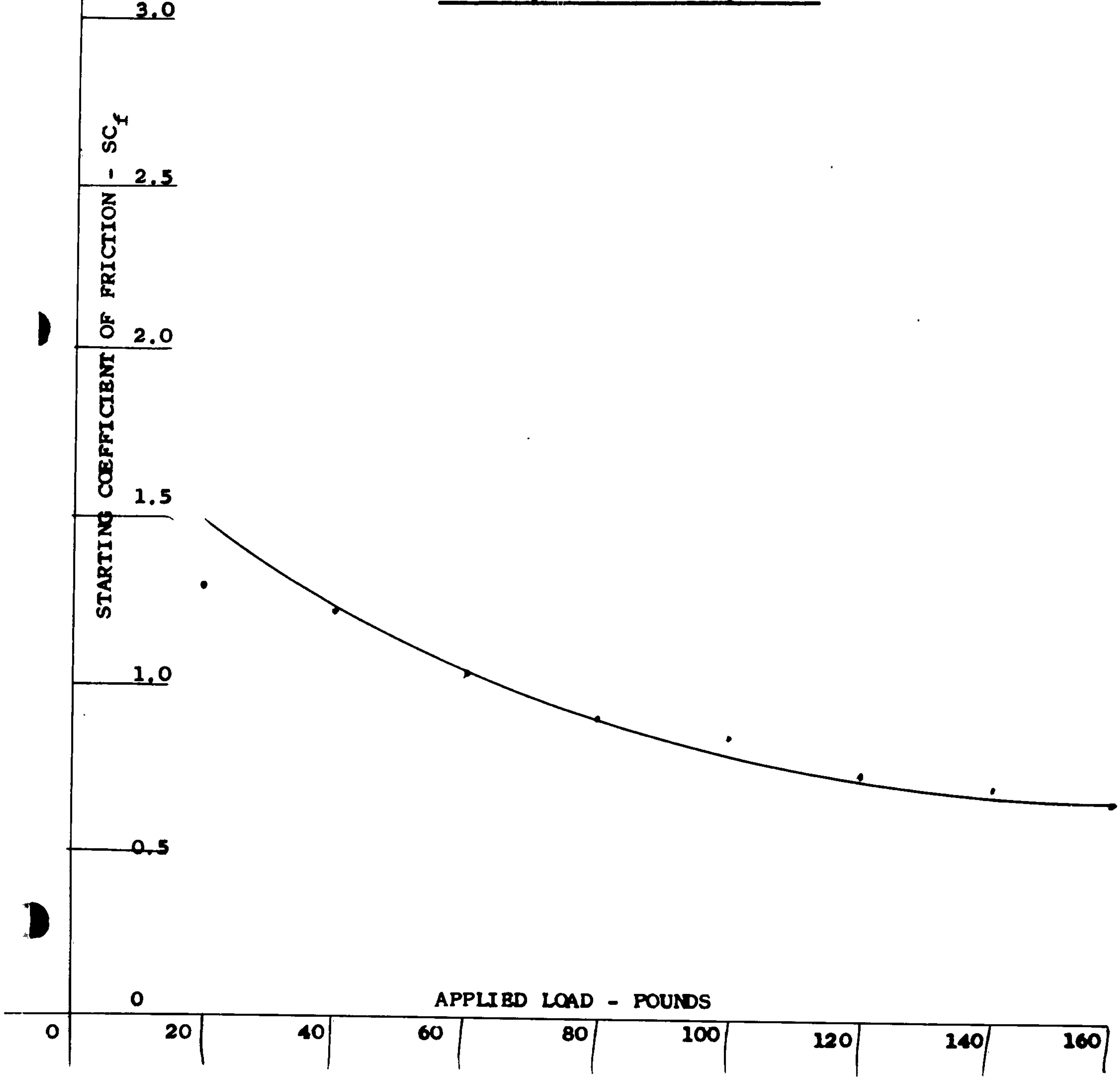


TABLE II

Starting Coefficient of Friction

Evaluation of Polysulfide Rubber - Varying Hardness Compounds

NOw-60-0123-C	11-AA	32-CC
Thiokol ST	100.0	100.0
Stearic Acid	0.5	0.5
G-M-F	1.5	1.5
Zinc Oxide	0.5	0.5
Philblack A Carbon Black	20.0	60.0
Statex B Carbon Black	30.0	30.0
	152.5	192.5

Cure - 30 minutes at 287°F

Test Velocity - 0.30 inches/minute

Applied Load - Pounds	FF	SC_f	FF	SC_f
20	18	0.90	13	0.65
40	30	0.75	26	0.65
60	44	0.73	38	0.63
80	54	0.68	58	0.73
100	56	0.56	62	0.62
120	77	0.64	79	0.66
140	82	0.59	97	0.69
160	80	0.50	105	0.66

Original Physical Properties - Cure 30 minutes at 287°F

Modulus at 100%, psi	550	1100
Tensile, psi	1320	1250
Elongation, %	320	110
Shore "A" Hardness	63	88

Figure 3

Starting Coefficient of Friction - Evaluation of Polysulfide Rubber - Varying Hardness Compounds

Polymer - Thiokol ST

Compound - NOw-60-0123-C-11-AA

Velocity - 0.30 inches/minute

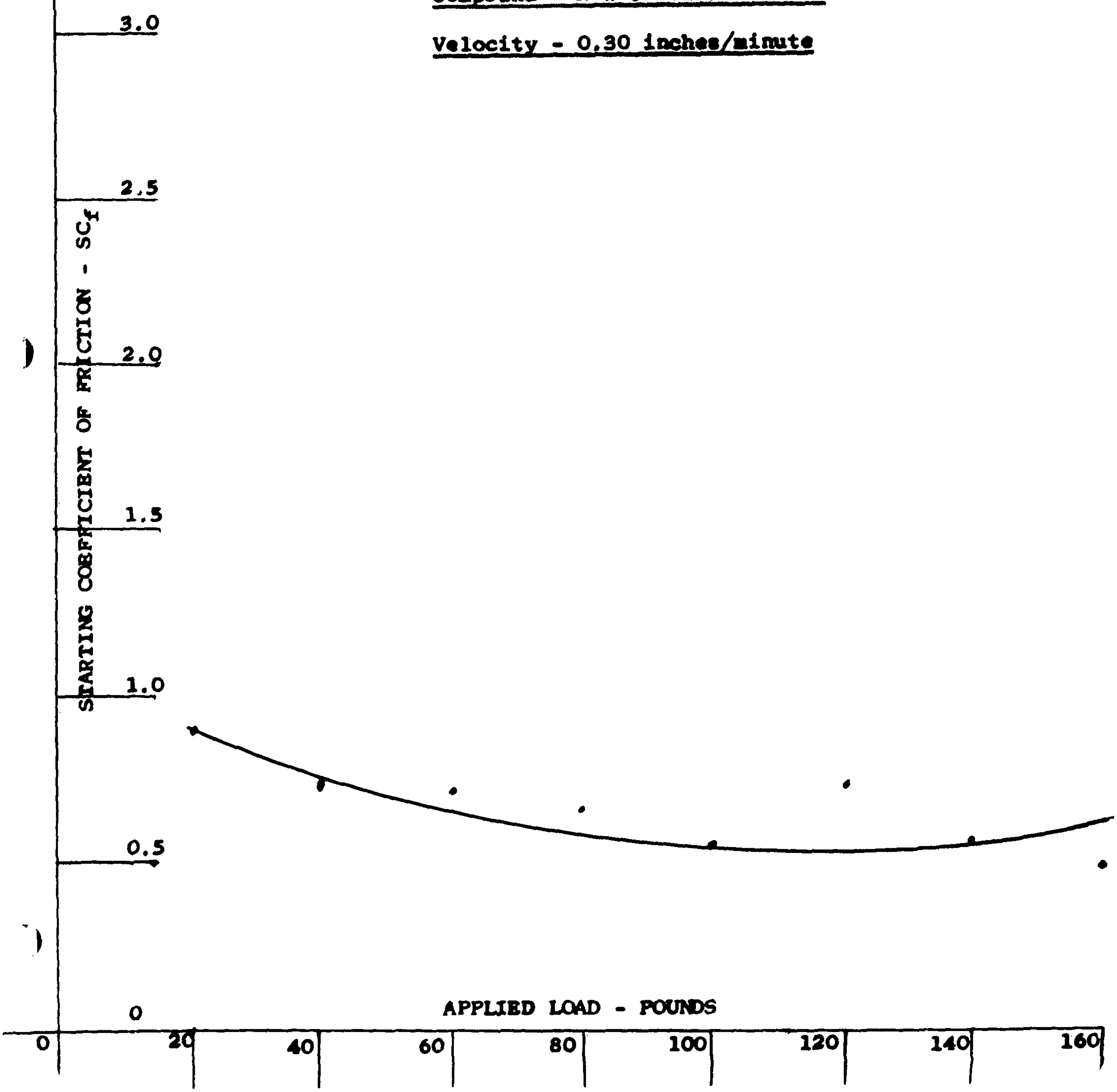


Figure 4

Starting Coefficient of Friction - Evaluation of

Polysulfide Rubber - Varying Hardness Compounds

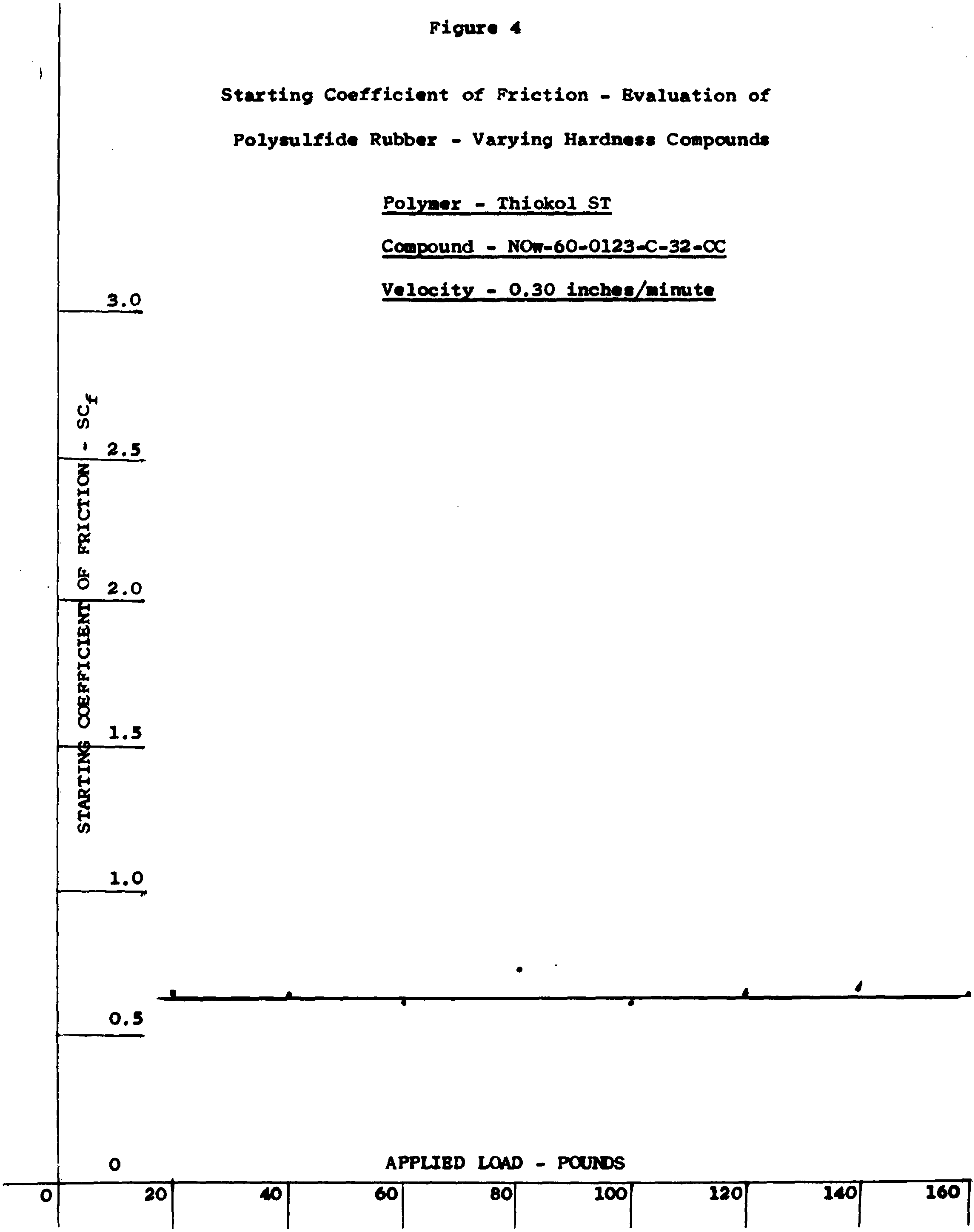


TABLE III

Starting Coefficient of Friction

Evaluation of Fluorocarbon Rubber - Varying Hardness Compounds

NOw-60-0123-C	33-CD	33-CF
Kel F Elastomer 3700	100.0	100.0
Zinc Oxide	10.0	10.0
Dyphos	10.0	10.0
Thermax MT Carbon Black	15.0	45.0
Diak #1	3.0	3.0
	138.0	168.0

Test Specimen Cure - Press Cure of 30 minutes at 300°F plus 16 hours at 300°F Air oven post cure

Test Velocity - 0.30 inches/minute

Applied Load - Pounds	FF	SC_f	FF	SC_f
20	22	1.10	22	1.10
40	40	1.00	37	0.93
60	46	0.77	48	0.80
80	61	0.76	46	0.58
100	61	0.61	64	0.64
120	86	0.72	76	0.63
140	104	0.74	68	0.49
160	109	0.68	92	0.58

Original Physical Properties - Press Cure of 30 Minutes at 300°F Plus 16 hours at 300°F Air Oven Post Cure

Modulus at 100%, psi	490	-
Tensile, psi	1800	2280
Elongation, %	180	90
Shore "A" Hardness	66	77

Figure 5

Starting Coefficient of Friction - Evaluation of Fluorocarbon Rubber - Varying Hardness Compounds

Polymer - Kel F Elastomer 3700

Compound - NOw-60-0123-C-33-CD

Velocity - 0.30 inches/minute

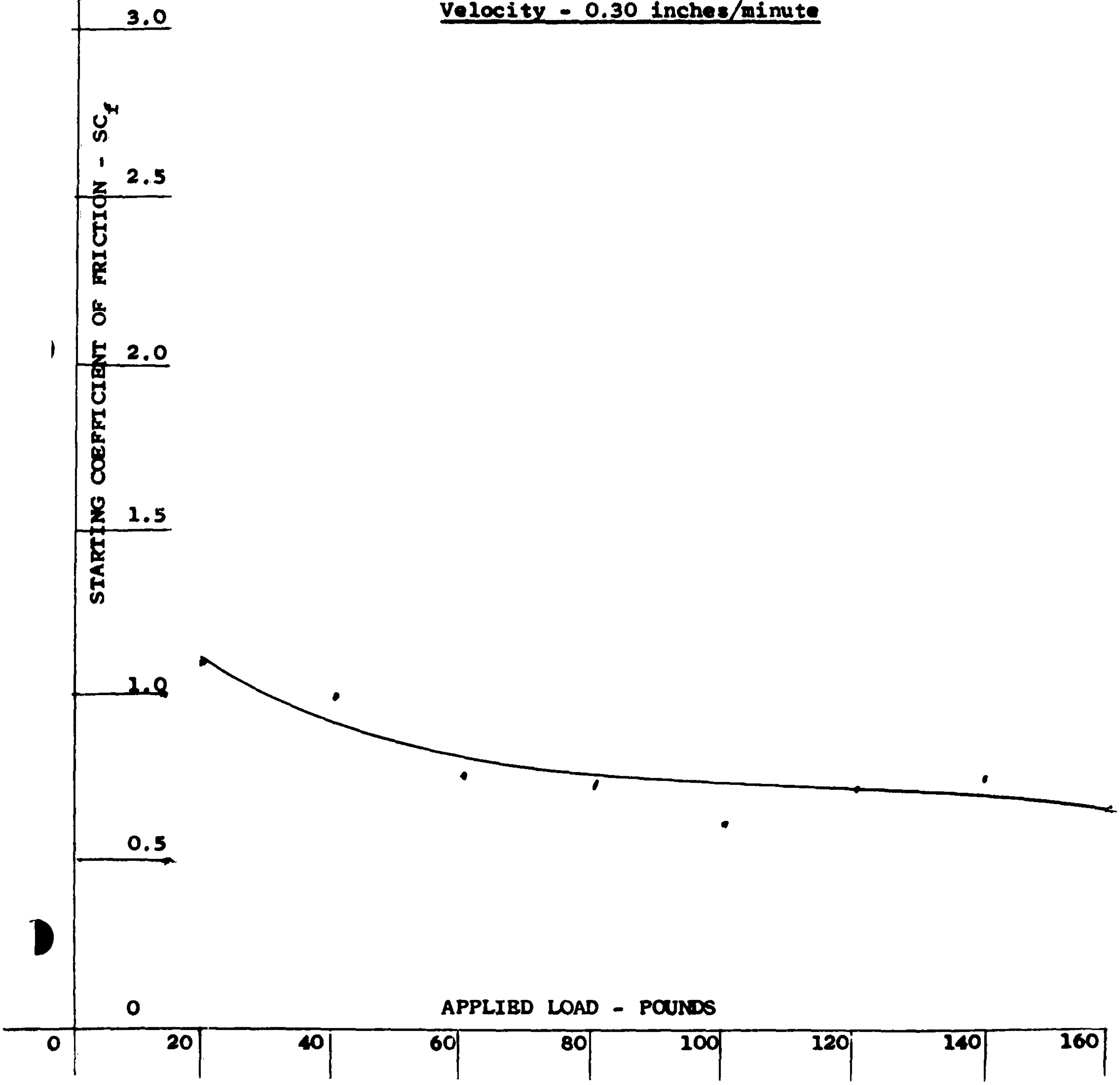


Figure 6

Starting Coefficient of Friction - Evaluation of Fluorocarbon Rubber - Varying Hardness Compounds

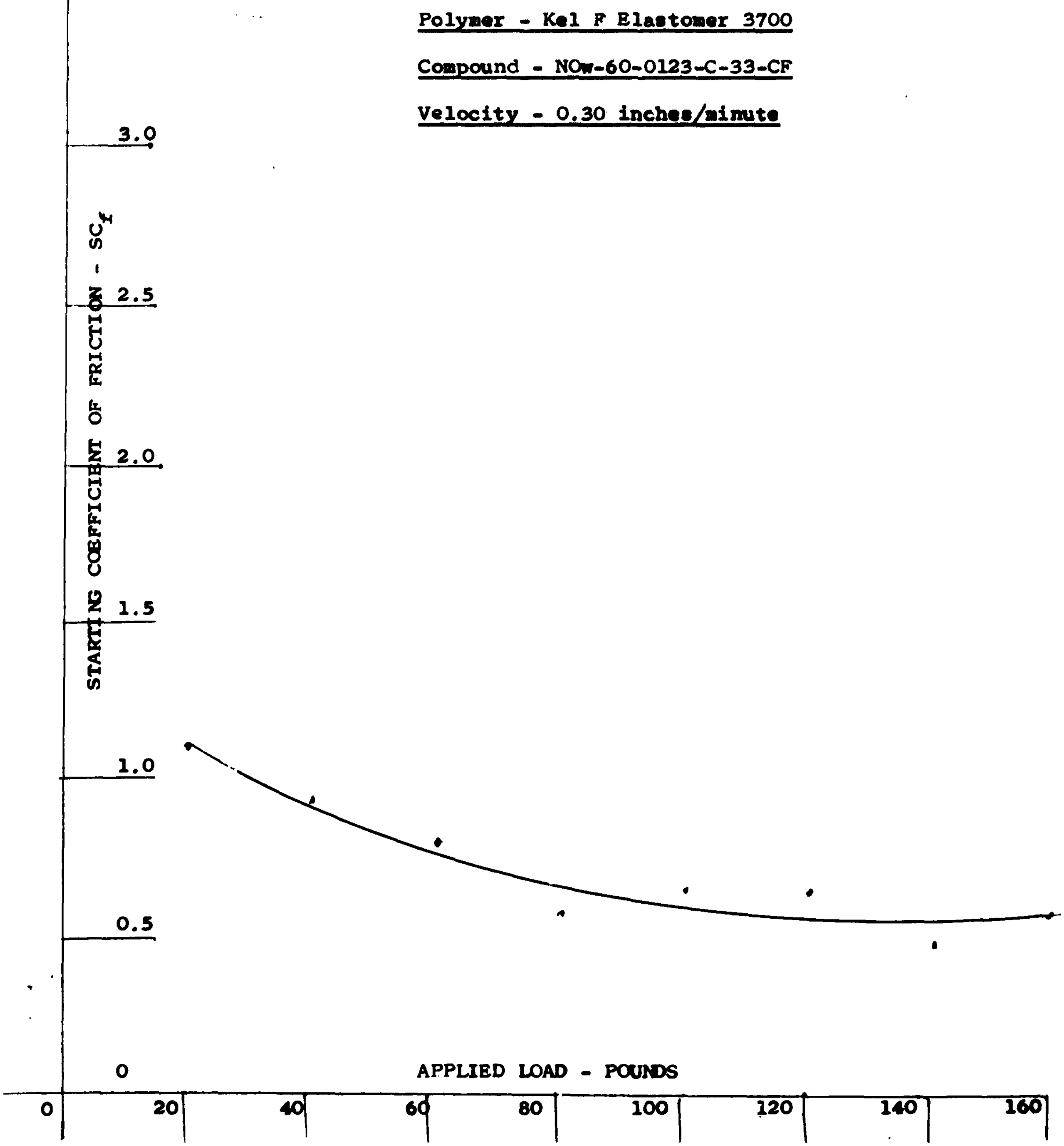


TABLE IV

Starting Coefficient of Friction

Evaluation of Fluorocarbon Rubber - Varying Hardness Compounds

NOw-60-0123-C	5-N	31-BZ
Viton A	100.0	100.0
Magnesium Oxide (Maglite K)	20.0	20.0
Thermax MT Carbon Black	20.0	60.0
Diak #1	1.5	1.5
	141.5	181.5

Test Specimen Cure - Press Cure of 30 minutes at 300°F plus Oven Post Cure as noted below

Test Velocity - 0.30 inches/minute

Applied Load - Pounds	FF	SC_f	FF	SC_f
20	23	1.15	21	1.05
40	26	0.65	32	0.80
60	18	0.30	43	0.72
80	32	0.40	48	0.60
100	30	0.30	75	0.75
120	47	0.38	53	0.53
140	58	0.42	64	0.46
160	62	0.39	73	0.46

Original Physical Properties - Press Cure of 30 minutes at 300°F - Post Cure as noted below.

Modulus at 100%, psi	1100	2130
Tensile, psi	2660	2130
Elongation, %	200	100
Shore "A" Hardness	70	85

Post Cure Procedure - Air Oven

1 hour at 200°F
1 hour at 250°F
1 hour at 300°F
1 hour at 350°F
24 hours at 400°F

Figure 7

Starting Coefficient of Friction - Evaluation of

Fluorocarbon Rubbers

POLYMER - VITON A

COMPOUND - NOw-60-0123-C-5-N

Velocity - 0.30 inches/minute

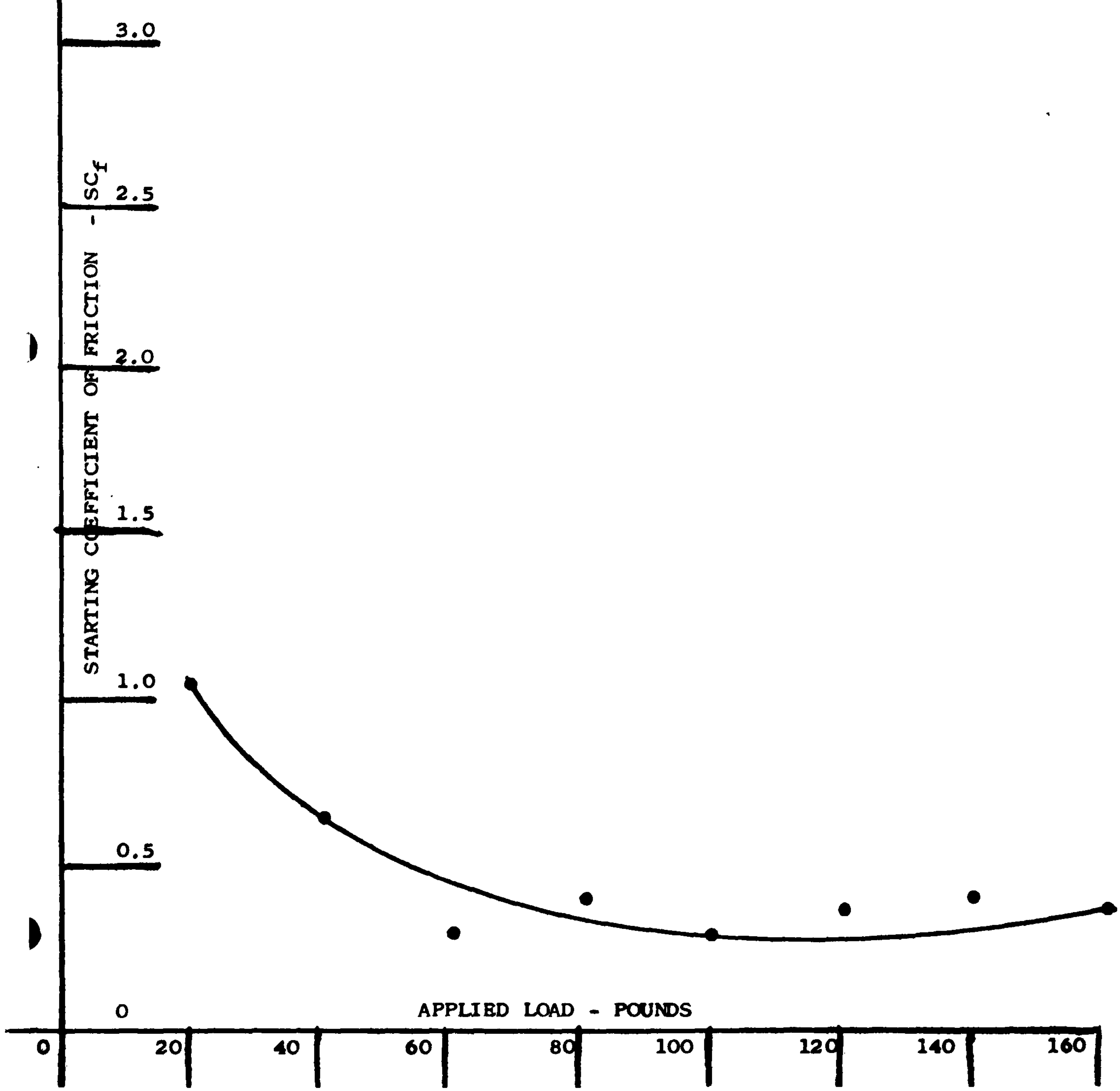


Figure 8

Starting Coefficient of Friction - Evaluation of Fluorocarbon Rubbers

Polymer - VITON A

Compound - NOw-60-0123-C-31-BZ

Velocity - 0.30 inches/minute

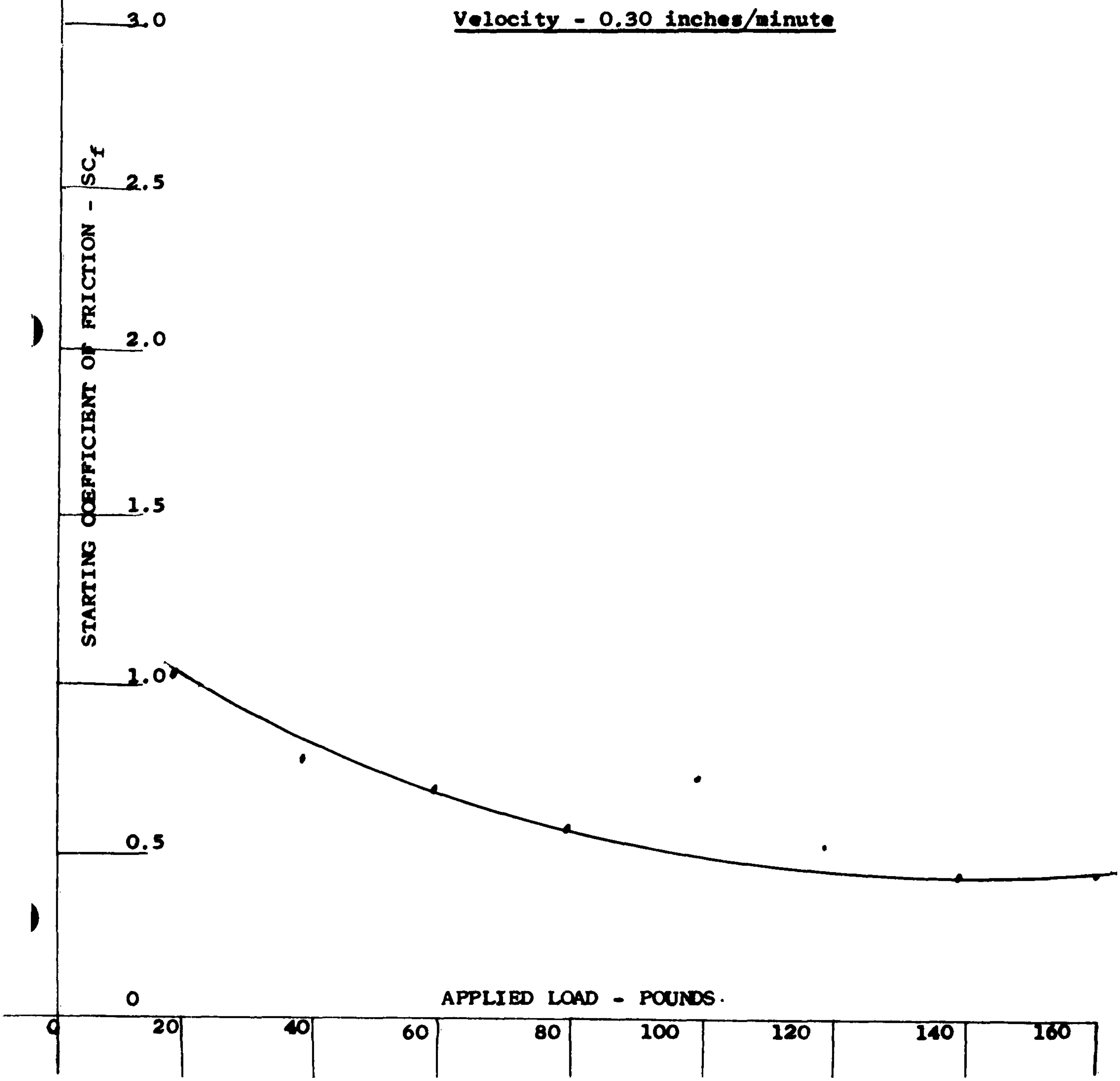


TABLE V

Starting Coefficient of Friction

Evaluation of Polyurethane Rubber - Varying Hardness Compounds

NOw-60-0123-C	30-BT	30-BU	30-BV	30-BW
Vibrathane 5003	100.00	100.00	100.00	100.00
Stearic Acid	0.25	0.25	0.50	1.00
Philblack O Carbon Black	-	20.00	40.00	80.00
DiCup 40-C	4.00	5.00	7.00	11.00
	104.25	125.25	147.50	192.00

Cure - 60 Minutes at 310°F

Test Velocity - 0.30 inches/minute

Applied Load-Pounds	FF	SC_f	FF	SC_f	FF	SC_f	FF	SC_f
20	52	2.60	48	2.40	28	1.40	18	0.90
40	76	1.90	90	2.25	55	1.38	45	1.13
60	92	1.53	114	1.90	61	1.02	59	0.98
80	128	1.60	166	2.08	87	1.09	83	1.04
100	142	1.42	168	1.68	94	0.94	94	0.94
120	160	1.33	188	1.57	122	1.02	87	0.73
140	139	0.99	210	1.50	146	1.04	34	0.96
160	166	1.04	220	1.38	173	1.08	172	1.08

Original Physical Properties - Cure 30 Minutes at 310°F

Modulus at 100%, psi	300	640	1550	2640
Tensile, psi	3390	4470	4430	3140
Elongation, %	460	430	250	110
Shore "A" Hardness	56	70	83	96

Figure 9

Starting Coefficient of Friction - Evaluation of

Polyurethane Rubber - Varying Hardness Compounds

Polymer - Vibrathane 5003

Compound - NOw-60-0123-C-30-BT

Velocity - 0.30 inches/minute

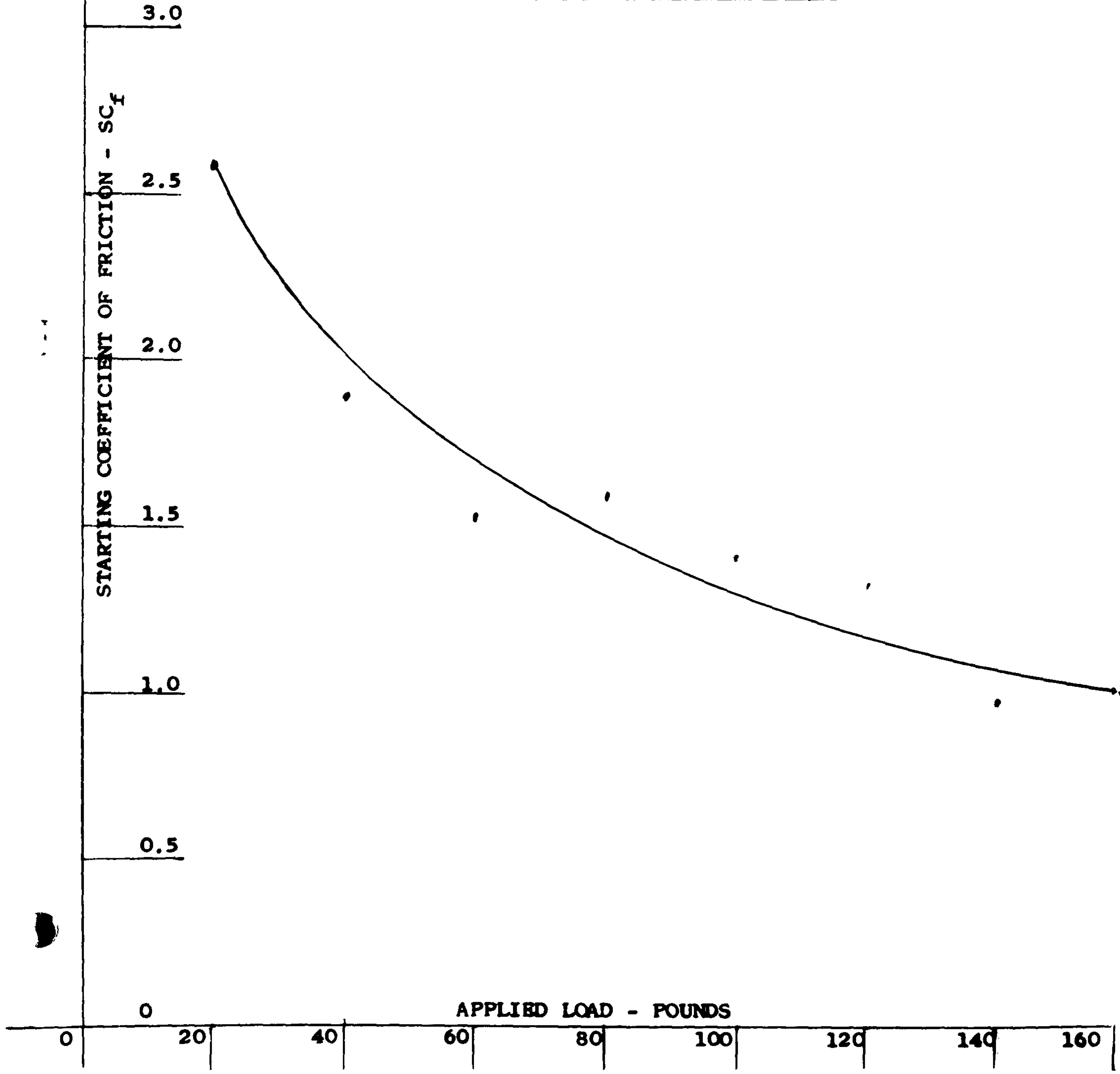


Figure 10

Starting Coefficient of Friction - Evaluation of

Polyurethane Rubber - Varying Hardness Compounds

Polymer - Vibrathane 5003

Compound - NOw-60-0123-C-30-BU

Velocity - 0.30 inches/minute

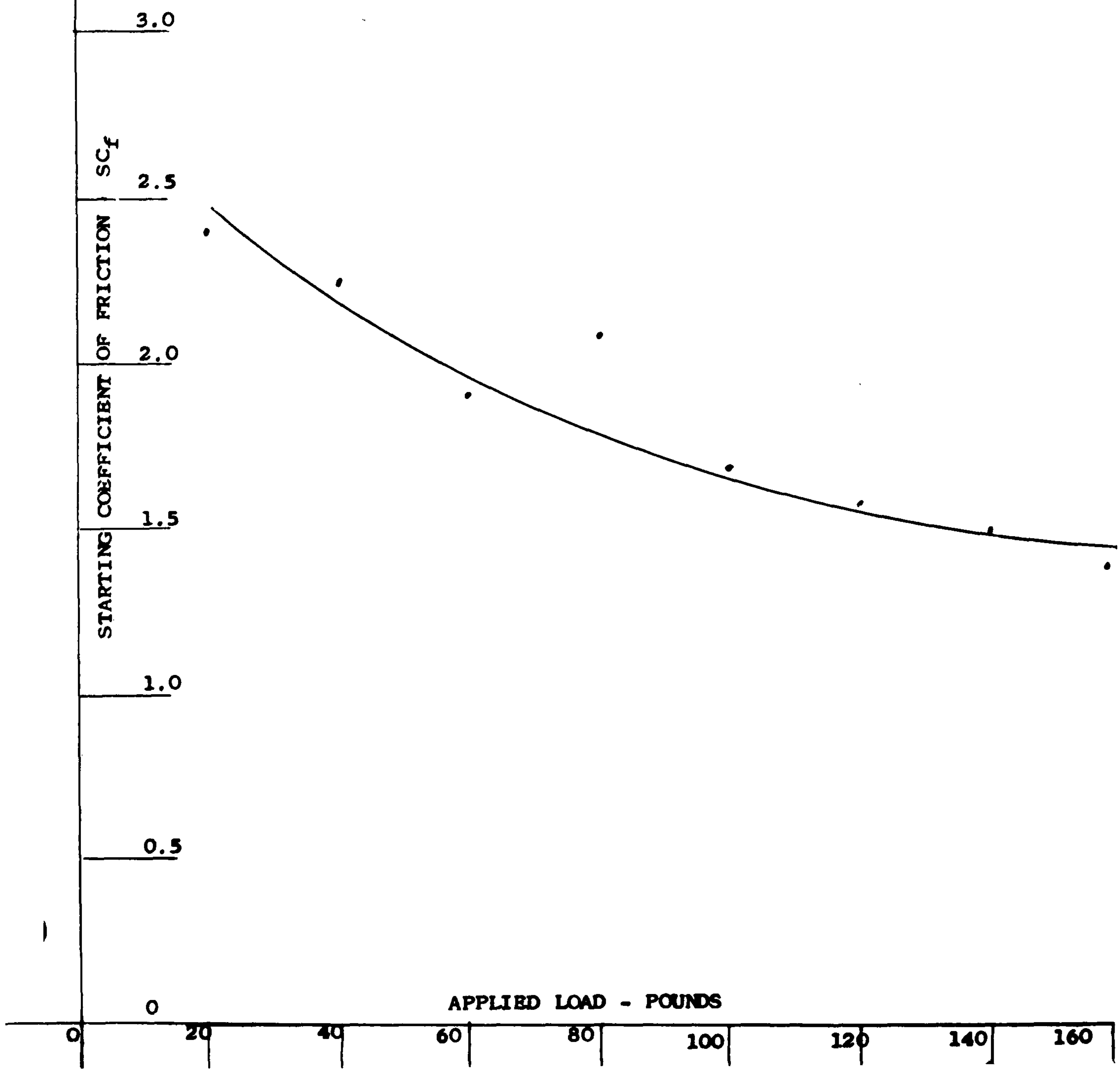


Figure 11

Starting Coefficient of Friction - Evaluation of

Polyurethane Rubber - Varying Hardness Compounds

Polymer - Vibrathane 5003

Compound - NOw-60-0123-C-30-BV

Velocity - 0.30 inches/minute

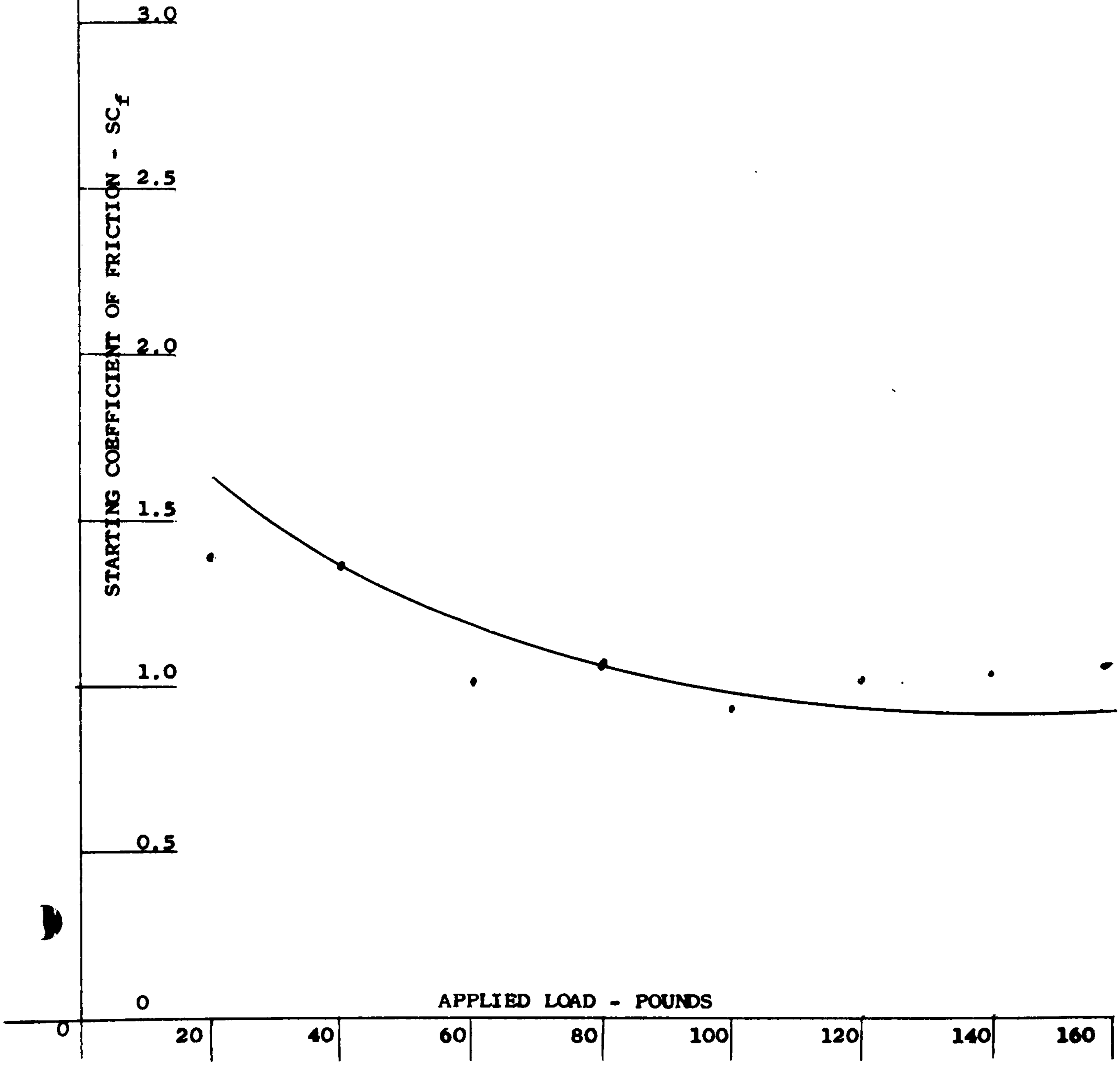


Figure 12

Starting Coefficient of Friction - Evaluation of

Polyurethane Rubber - Varying Hardness Compounds

<u>Polymer - Vibrathane 5003</u>

<u>Compound - NOw-60-0123-C-30-BW</u>

<u>Velocity - 0.30 inches/minute</u>

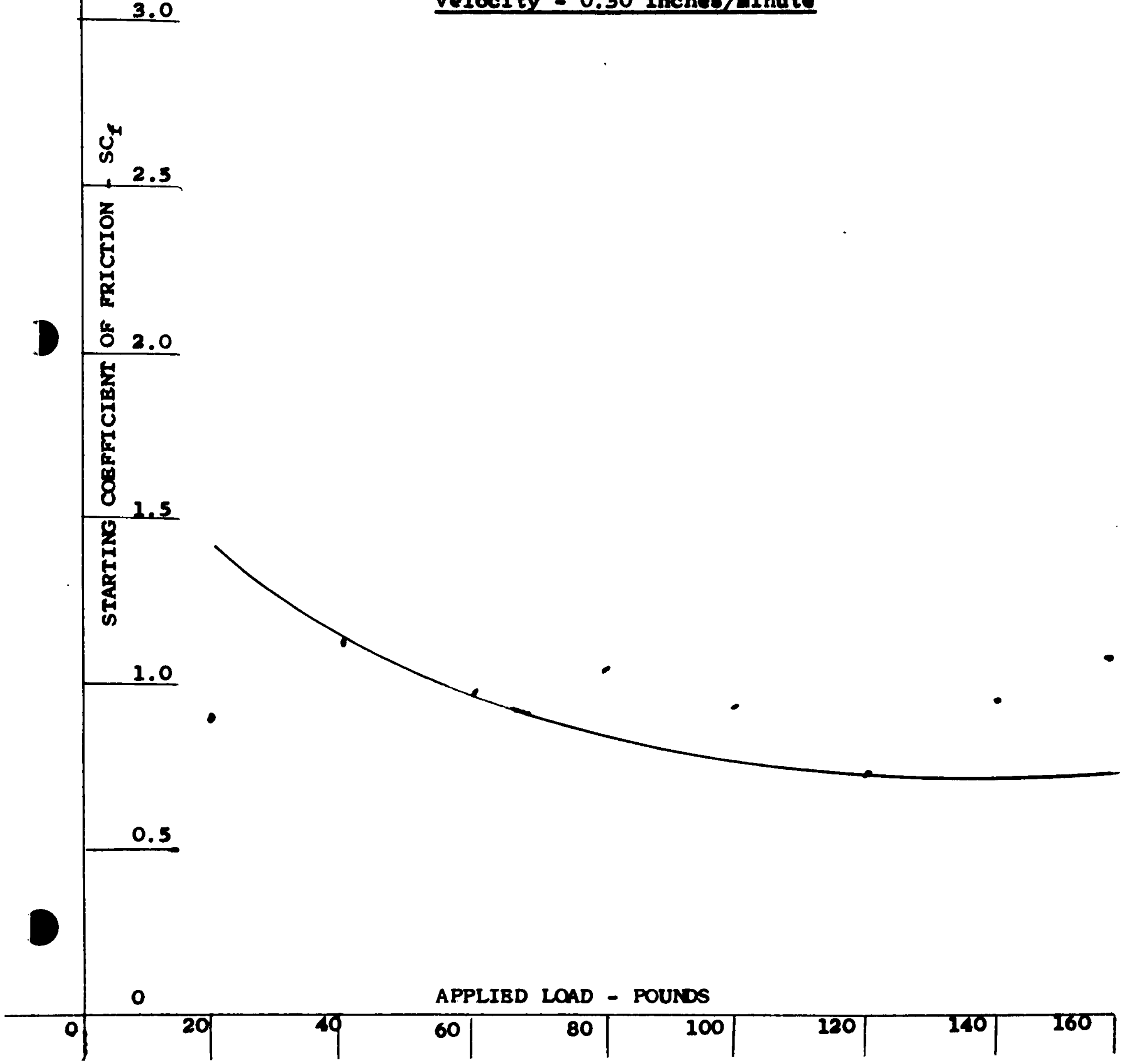


TABLE VI

Starting Coefficient of Friction

Evaluation of Teflon Coated Nitrile Rubber

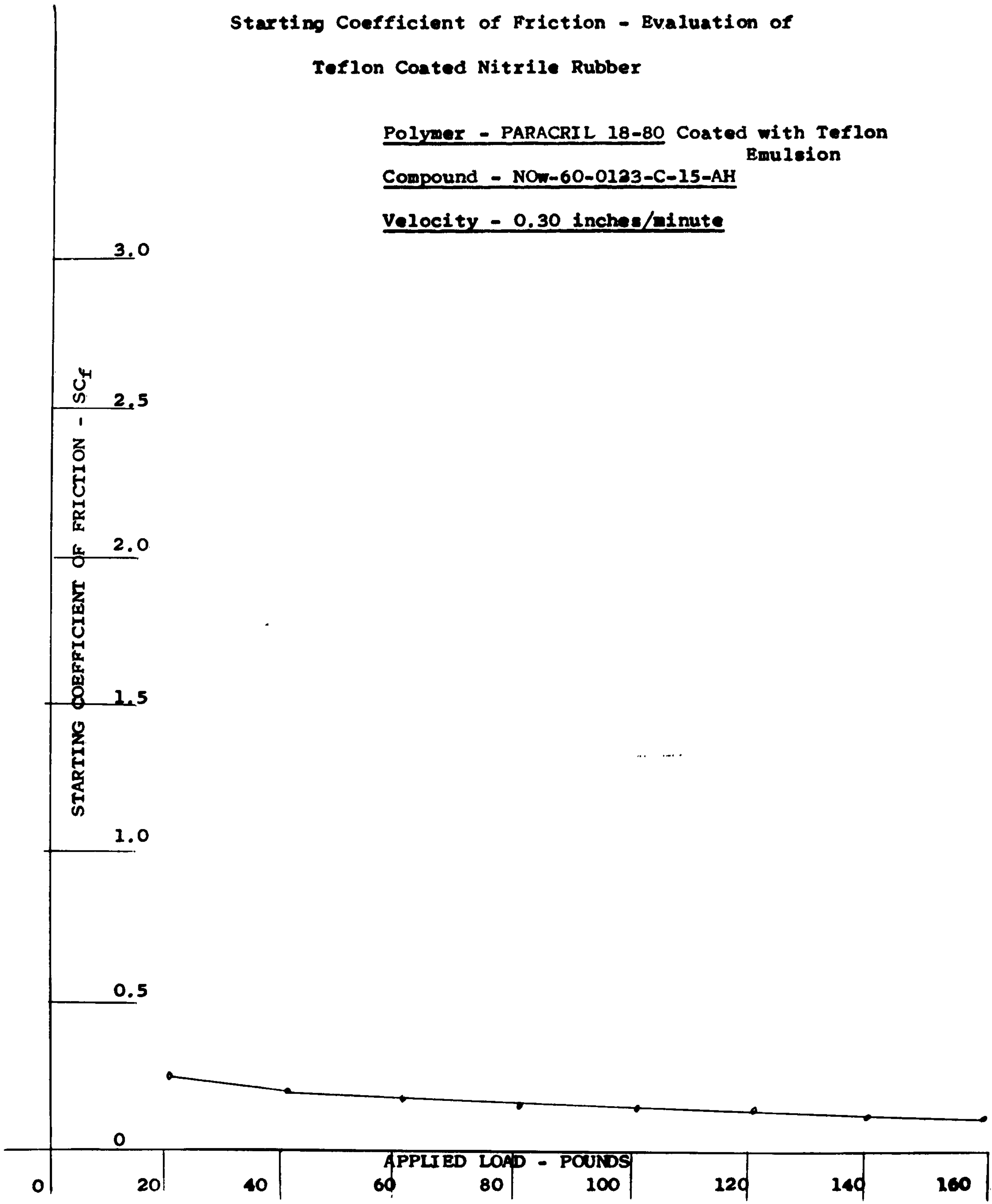
NOw-60-0123-C	15-AH
PARACRIL 18-80	100.0
Zinc Oxide	10.0
AMINOX	2.0
Wyex Carbon Black	25.0
Pelletex Carbon Black	75.0
Paraplex G-25	10.0
Plasticizer SC	7.5
TP-95 Plasticizer	7.5
TUEX	1.5
Tetrone A	1.5
	240.0

Test specimens cured 30 minutes at 310°F. Submitted to Mr. E. J. Kohn of Naval Research Laboratories and coated with Teflon emulsion.

Test Velocity - 0.30 inches/minute

Applied Load - Pounds	FF	SC_f
20	5	0.25
40	8	0.20
60	12	0.19
80	13	0.16
100	16	0.16
120	18	0.15
140	18	0.13
160	17	0.11

Figure 13



Starting Coefficient of Friction - Evaluation of
Teflon Coated Nitrile Rubber
Polymer - PARACRIL 18-80 Coated with Teflon Emulsion
Compound - NOw-60-0123-C-15-AH
Velocity - 0.30 inches/minute
STARTING COEFFICIENT OF FRICTION - SC_f
3.0
2.5
2.0
1.5
1.0
0.5
0
APPLIED LOAD - POUNDS
0
20
40
60
80
100
120
140
160

TABLE VII

Starting Coefficient of Friction

Evaluation of Teflon Fabrics Laminated to

Butadiene-Acrylonitrile Rubber Compounds

NOw-60-0123-C	3-C	50-DU	50-DV	50-DW	50-DX
		Circular knit fabric made of a 50/50 blend by weight of cotton and "Teflon" fibers (5.5 singles yarn) laminated and mechanically bonded to compound 3-C.	Circular knit fabric made of 800/120"Teflon" textured fiber laminated and mechanically, etc.	Double woven fabric containing "Teflon" fiber on one surface and cottn on other.Cotton surface laminated and, etc.	"Teflon woven fabric with one surface napped or brushed napped surface laminated and mechanically bonded to compound 3-C.
PARACRIL 18-80	100.0				
Zinc Oxide	10.0				
AMINOX	2.0				
Wyex Carbon Black	25.0				
Pelletex Carbon Blk	75.0				
Paraplex G-25	10.0				
Plasticizer SC	7.5				
TP-95 Plasticizer	7.5				
TUEX	1.5				
Tetrone A	1.5				
	240.0				

Cure - 30 minutes at 310°F

Test Velocity - 0.30 inches/minute

Applied Load Pounds	FF	SC_f	FF	SC_f	FF	SC_f	FF	SC_f	FF	SC_f
20	42	2.10	4	0.20	0.25	0.01	0.25	0.01	0.5	0.03
40	62	1.55	9	0.23	2.5	0.06	2.5	0.06	3	0.08
60	72	1.20	14	0.23	6	0.10	5.5	0.09	4.5	0.08
80	85	1.06	17	0.21	14	0.18	5	0.06	5.5	0.07
100	98	0.98	27	0.27	15	0.15	7	0.07	6.5	0.07
120	95	0.79	33	0.28	18.5	0.15	9	0.08	8.5	0.07
140	107	0.76	46	0.33	22	0.16	9.5	0.07	8.5	0.06
160	113	0.71	49	0.31	28	0.18	9.5	0.06	11	0.07

Original Physical Properties - Cure 30 minutes at 310°F

	3-C	50-DU	50-DV	50-DW	50-DX
Modulus @ 100%,psi	700	-	-	-	-
Tensile, psi	1860	-	-	-	-
Elongation, %	200	-	-	-	-
Shore "A" Hardness	69	-	-	-	-

Note: Manual adhesion tests on the various "Teflon" fabrics laminated and mechanically bonded to compound NOw-60-0123-C described above indicated excellent adhesion, particularly the fabric used in 50-DX.

Figure 14

Starting Coefficient of Friction - Evaluation of Teflon Fabrics Laminated to Butadiene-Acrylonitrile Rubber Compounds

Polymer - PARACRIL 18-80

Compound - NOw-60-0123-C[illegible]3-C

Velocity - 0.30 inches/minute

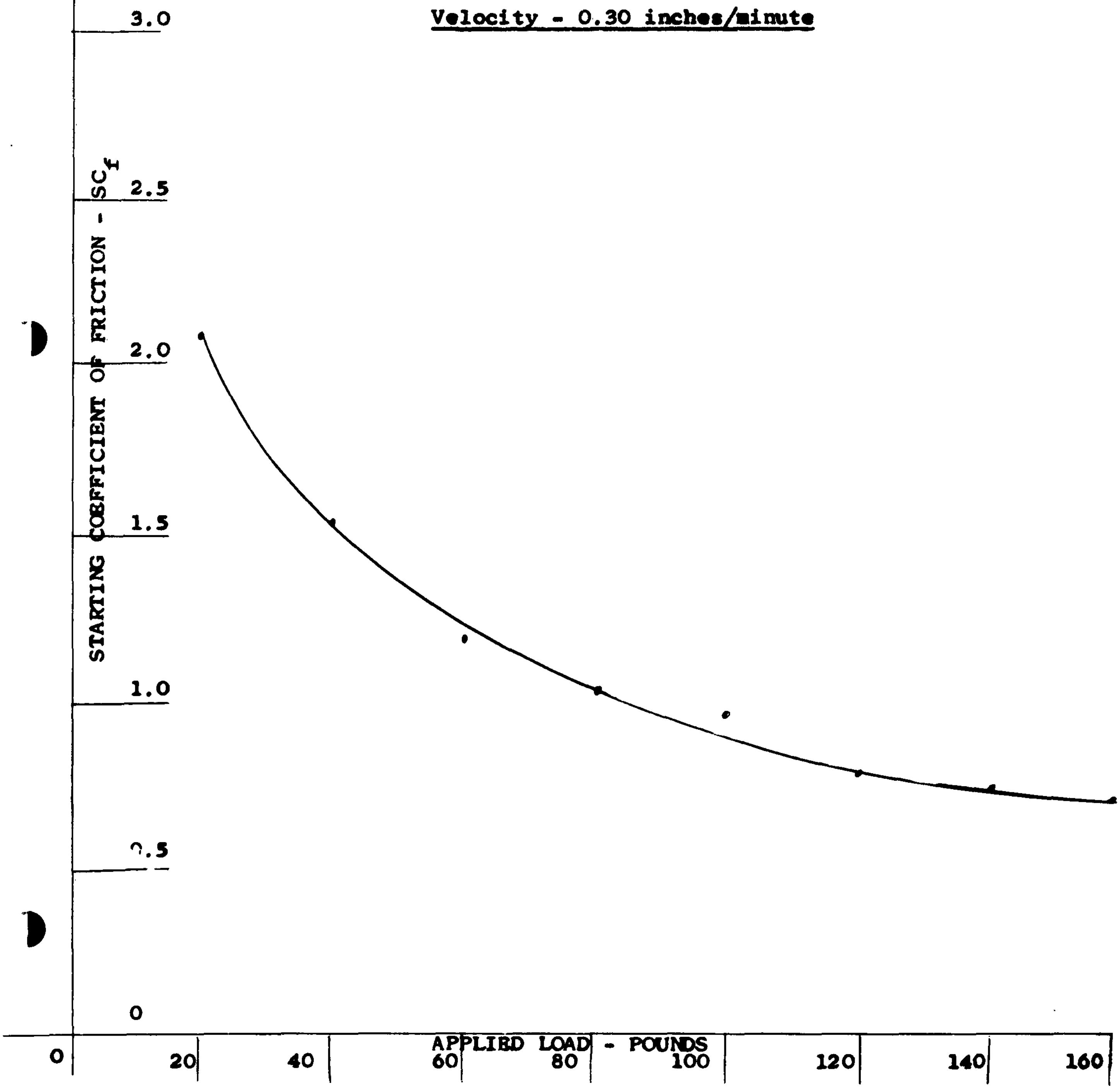


Figure 15

Starting Coefficient of Friction - Evaluation of

Teflon Fabrics Laminated to Butadiene-Acrylonitrile Rubber Compounds

Polymer - PARACRIL 18-80

Compound - NOw-60-0123-C-50-DU

Velocity - 0.30 inches/minute

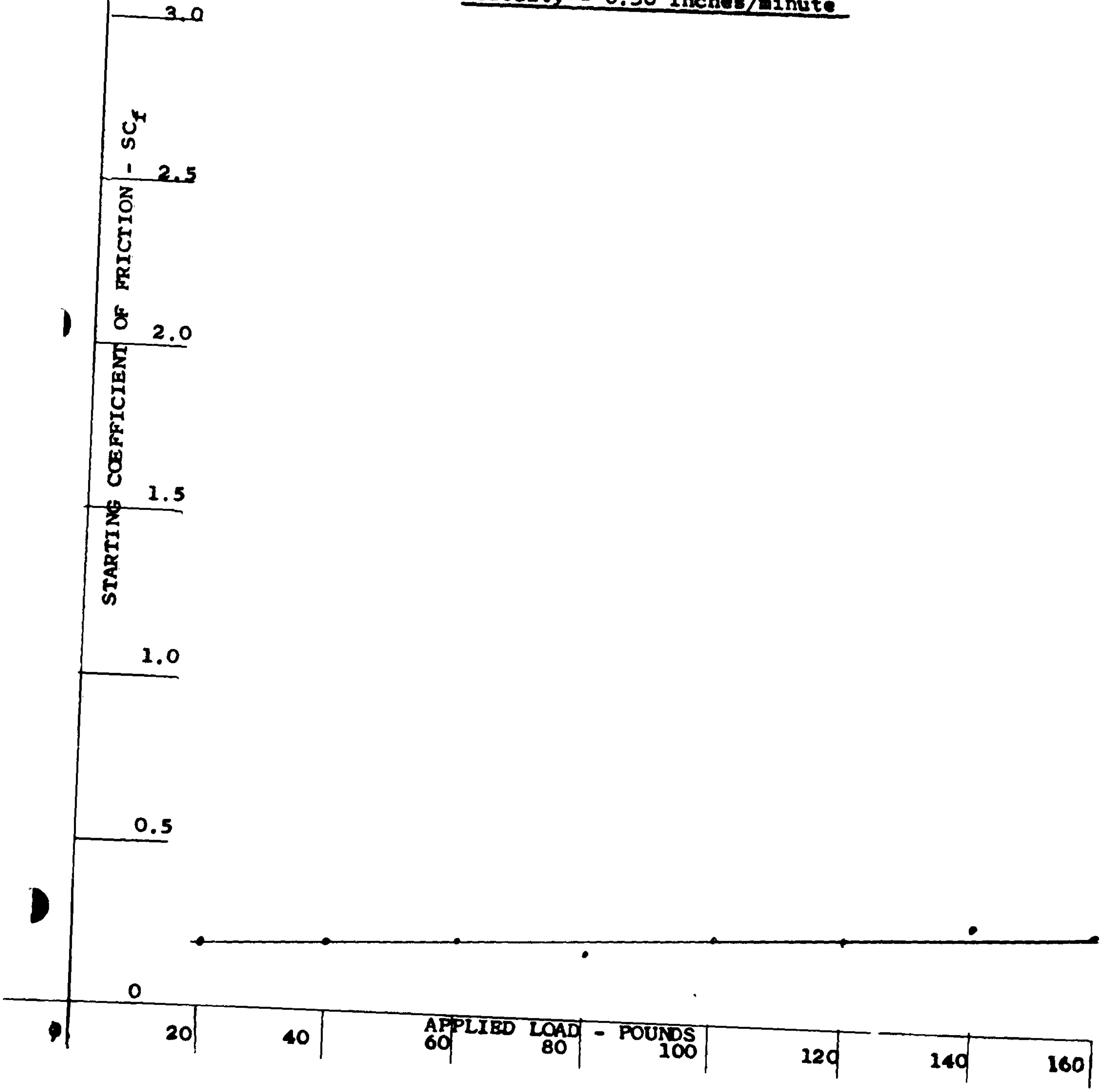


Figure 16

Starting Coefficient of Friction - Evaluation of

Teflon Fabrics Laminated to Butadiene-Acrylonitrile Rubber Compounds

Polymer - PARACRIL 18-80

Compound - NOw-60-0123-C-50-DV

Velocity - 0.30 inches/minute

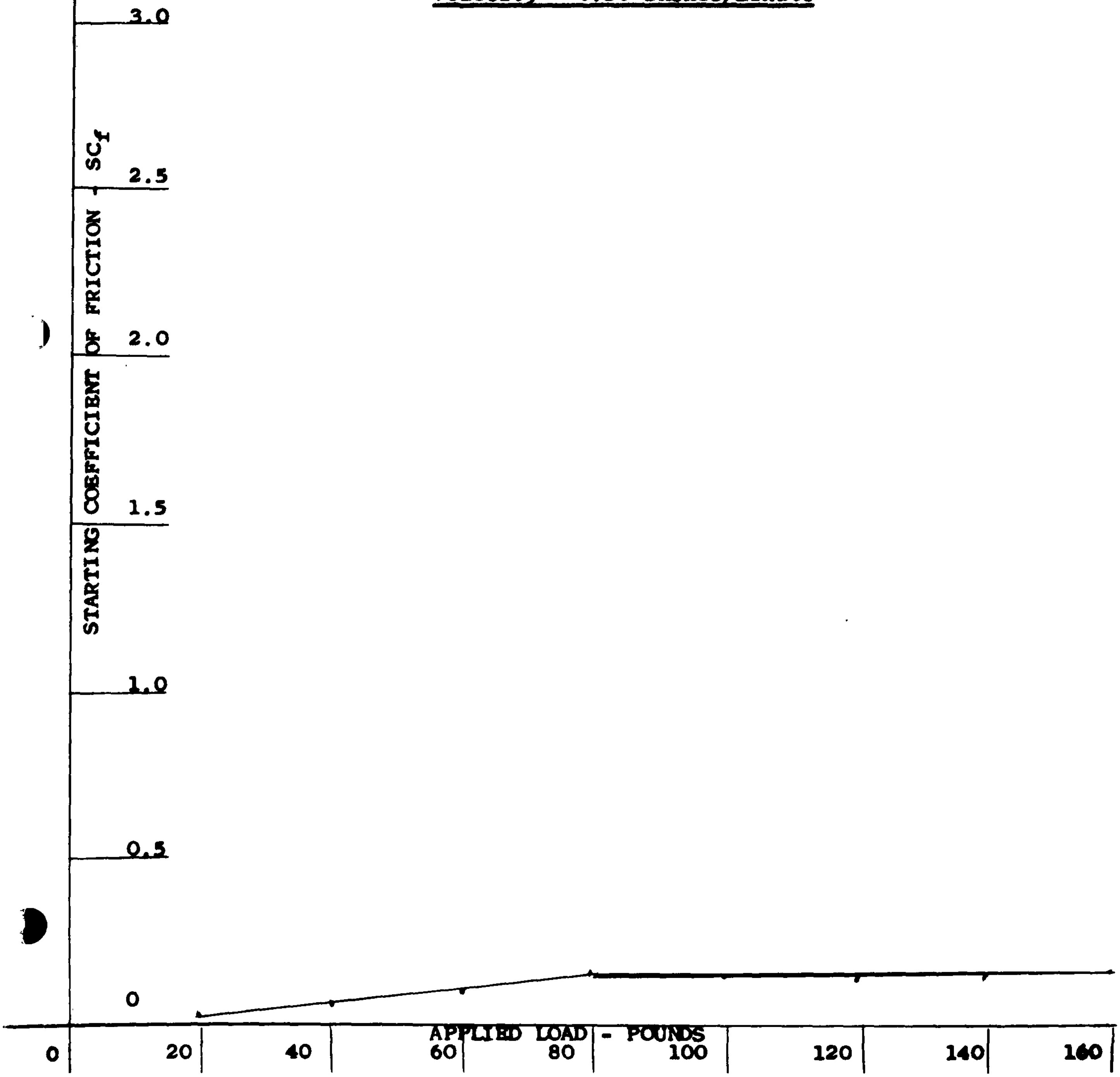


Figure 17

Starting Coefficient of Friction - Evaluation of

Teflon Fabrics Laminated to Butadiene-Acrylonitrile Rubber Compounds

Polymer - PARACRIL 18-80

Compound - NOw-60-0123-C-50-DW

Velocity - 0.30 inches/minute

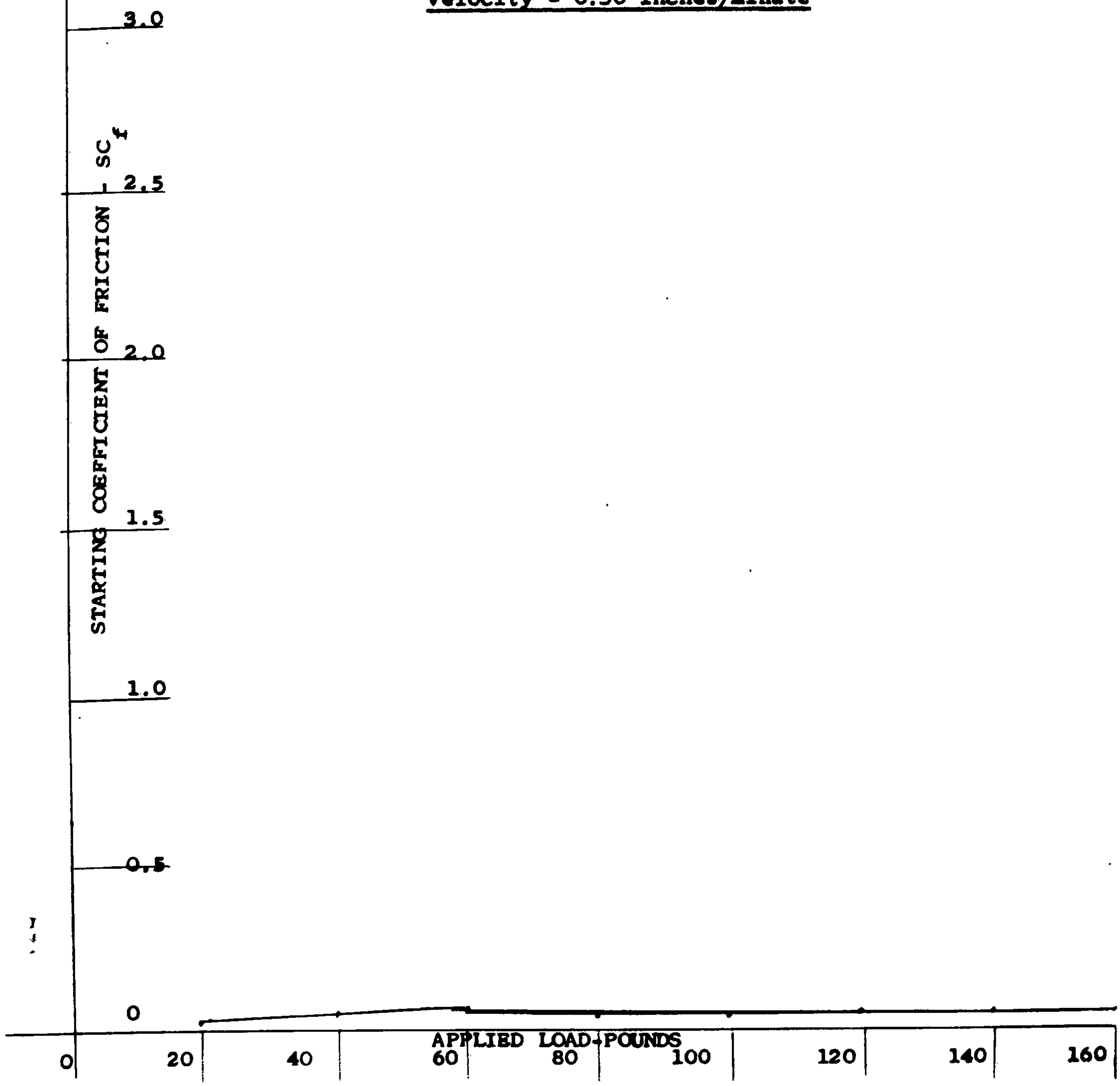


Figure 18

Starting Coefficient of Friction - Evaluation of

Teflon Fabrics Laminated to Butadiene-Acrylonitrile Rubber Compounds

Polymer - PARACRIL 18-80

Compound - NOw-60-0123-C-50-DX

Velocity - 0.30 inches/minute

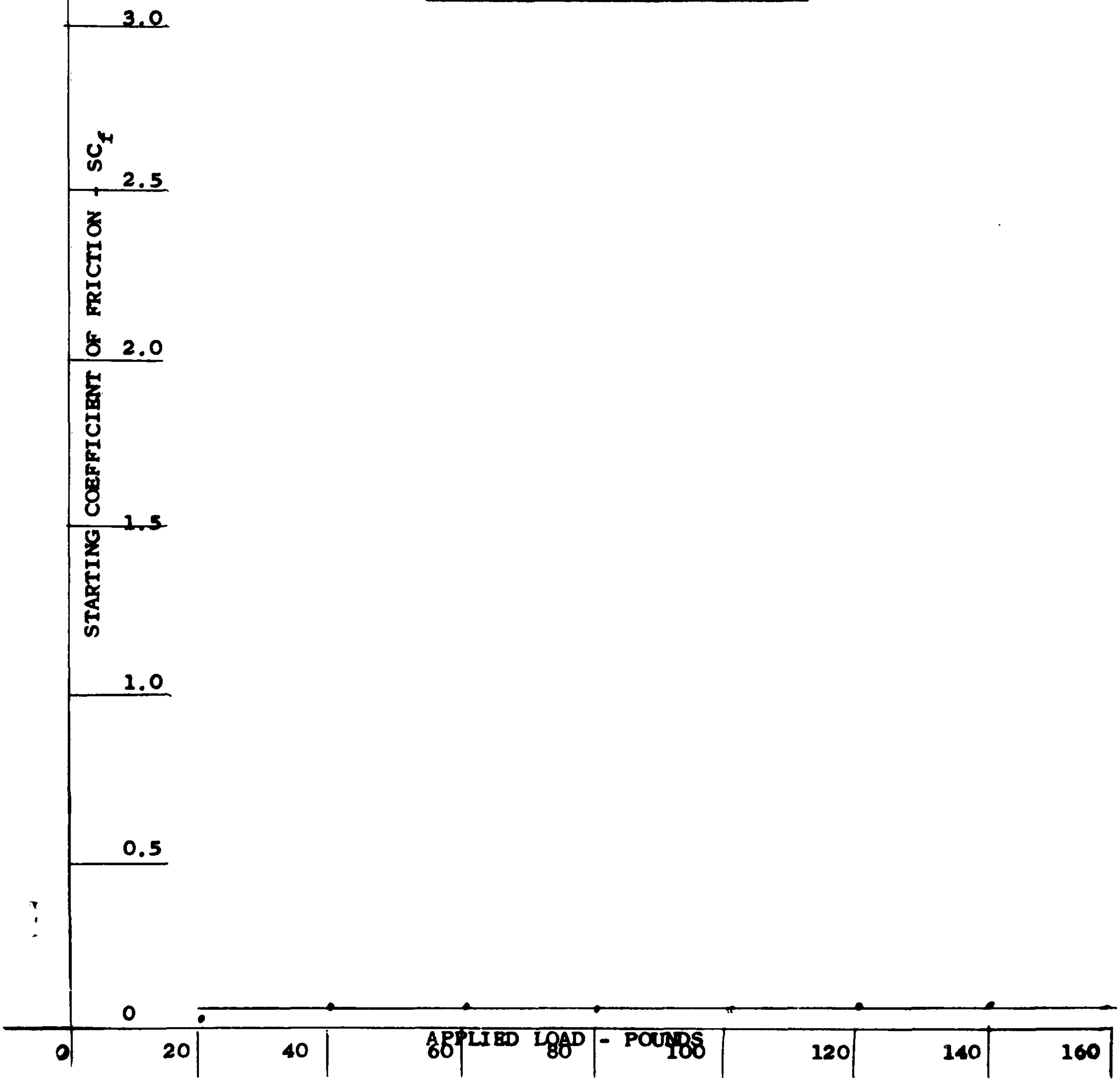


TABLE VIII

Starting Coefficient of Friction

Evaluation of Various Rubber Compounds Treated With

Quantum "Slippery" Rubber Process

NOw-60-0123-C	63-FM		63-FN		63-FO		63-FP		63-FQ	
Former NOw-60-0123-C Compound	3-C		18-AK		19-AQ		19-AO		7-Q	
Rubber	PARACRIL 18-80		Ethylene Propylene EP-931		NAUGAPOL 1015		NAUGATUCK Polybutadiene		Ethylene Propylene EPR J-9028-A	
Untreated Samples Applied Load-Pounds	FF	SC_f	FF	SC_f	FF	SC_f	FF	SC_f	FF	SC_f
20	42	2.10	44	2.20	52	2.60	54	2.70	53	2.65
40	62	1.55	83	2.08	64	1.60	57	1.43	97	2.43
60	72	1.20	108	1.80	84	1.40	64	1.07	124	2.07
80	85	1.06	123	1.53	95	1.19	76	0.95	150	1.88
100	98	0.98	138	1.38	105	1.05	80	0.80	152	1.53
120	95	0.79	142	1.18	106	0.88	80	0.67	165	1.38
140	107	0.76	152	1.09	110	0.79	85	0.61	170	1.21
160	113	0.71	138	0.86	112	0.70	88	0.55	180	1.13
"Slippery" Rubber Process Treated Samples Applied Load-Pounds	FF	SC_f	FF	SC_f	FF	SC_f	FF	SC_f	FF	SC_f
20	4	0.20	19	0.95	6	0.30	7	0.35	11	0.55
40	12	0.30	38	0.95	10	0.25	10	0.25	25	0.63
60	18	0.30	58	0.97	16	0.27	17	0.28	38	0.63
80	24	0.30	79	0.99	26	0.32	20	0.25	58	0.73
100	26	0.26	90	0.90	28	0.28	25	0.25	77	0.77
120	34	0.28	100	0.83	30	0.25	30	0.25	98	0.82
140	38	0.27	114	0.81	46	0.33	38	0.27	106	0.78
160	41	0.26	121	0.76	56	0.35	48	0.38	128	0.80

Figure 19

Starting Coefficient of Friction - Evaluation of

Various Rubber Compounds Treated with Quantum "Slippery" Rubber Process

Polymer - PARACRIL 18-80 (untreated)

Compound - NOw-60-0123-C-3-C

Velocity - 0.30 inches/minute

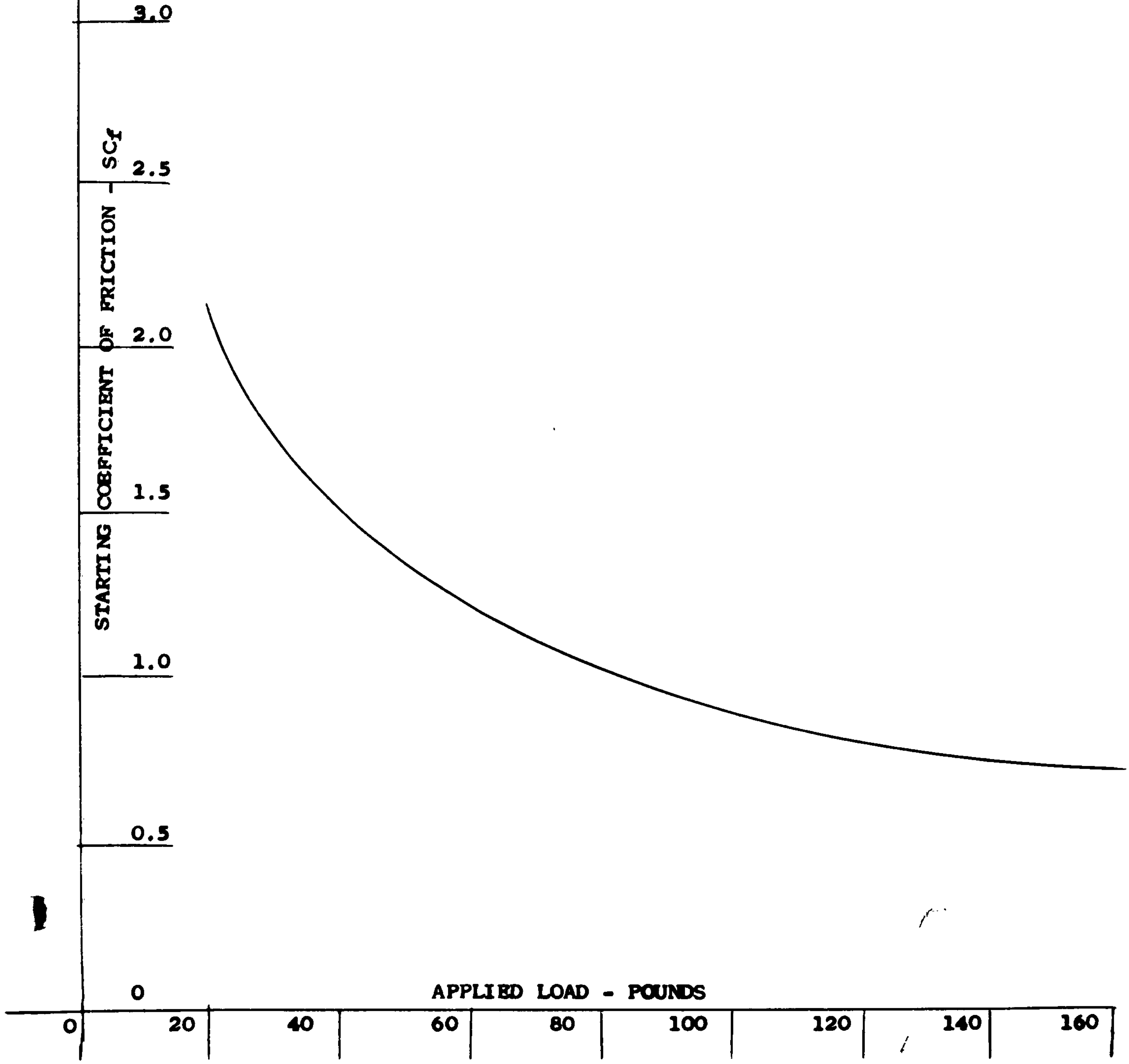


Figure 20

Starting Coefficient of Friction - Evaluation of

Various Rubber Compounds Treated with Quantum "Slippery" Rubber Process

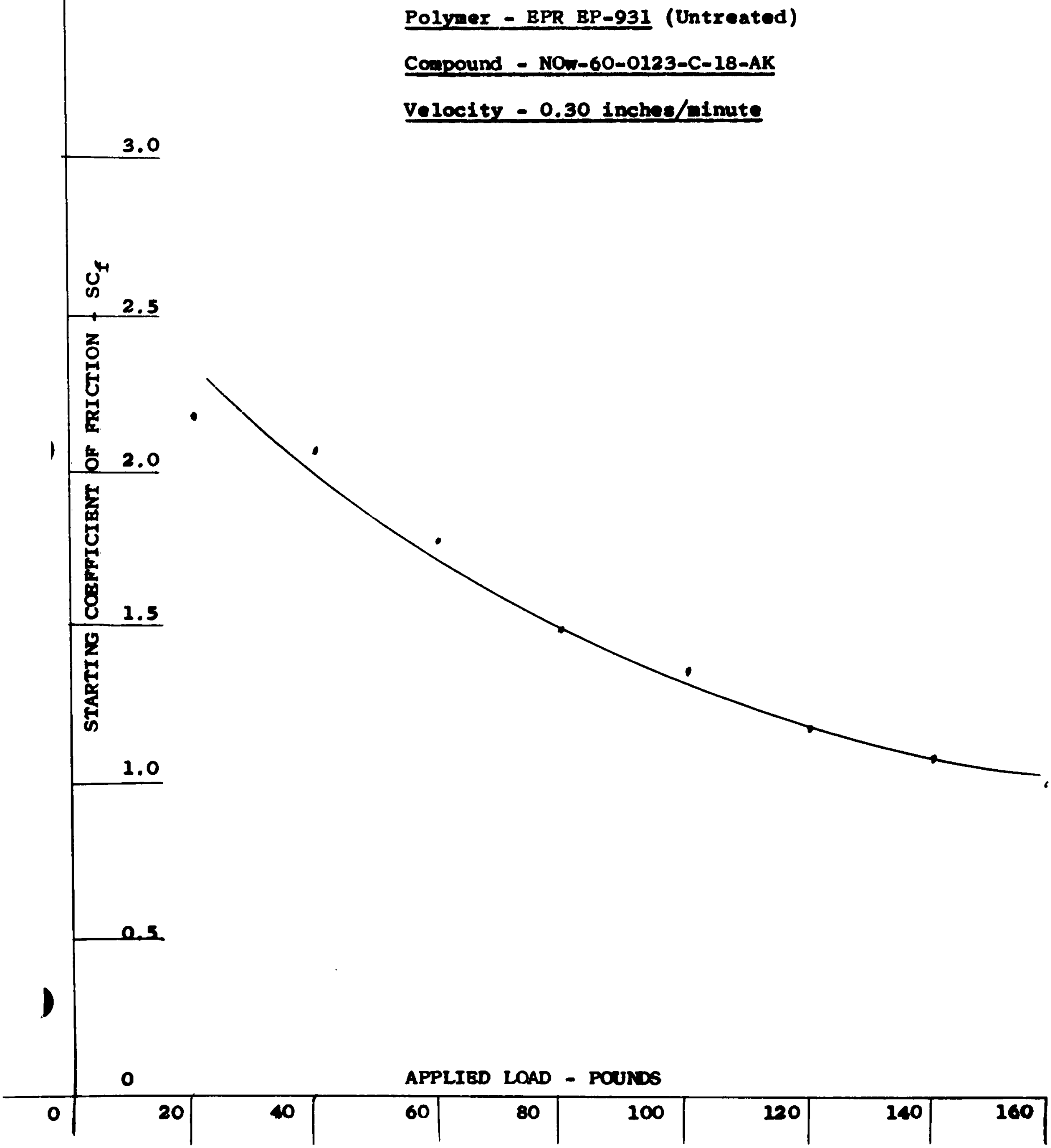


Figure 21

Starting Coefficient of Friction - Evaluation of

Various Rubber Compounds Treated with Quantum "Slippery" Rubber Process

Polymer - NAUGAPOL 1015 (Untreated)

Compound - NOw-60-0123-C-19-AQ

Velocity - 0.30 inches/minute

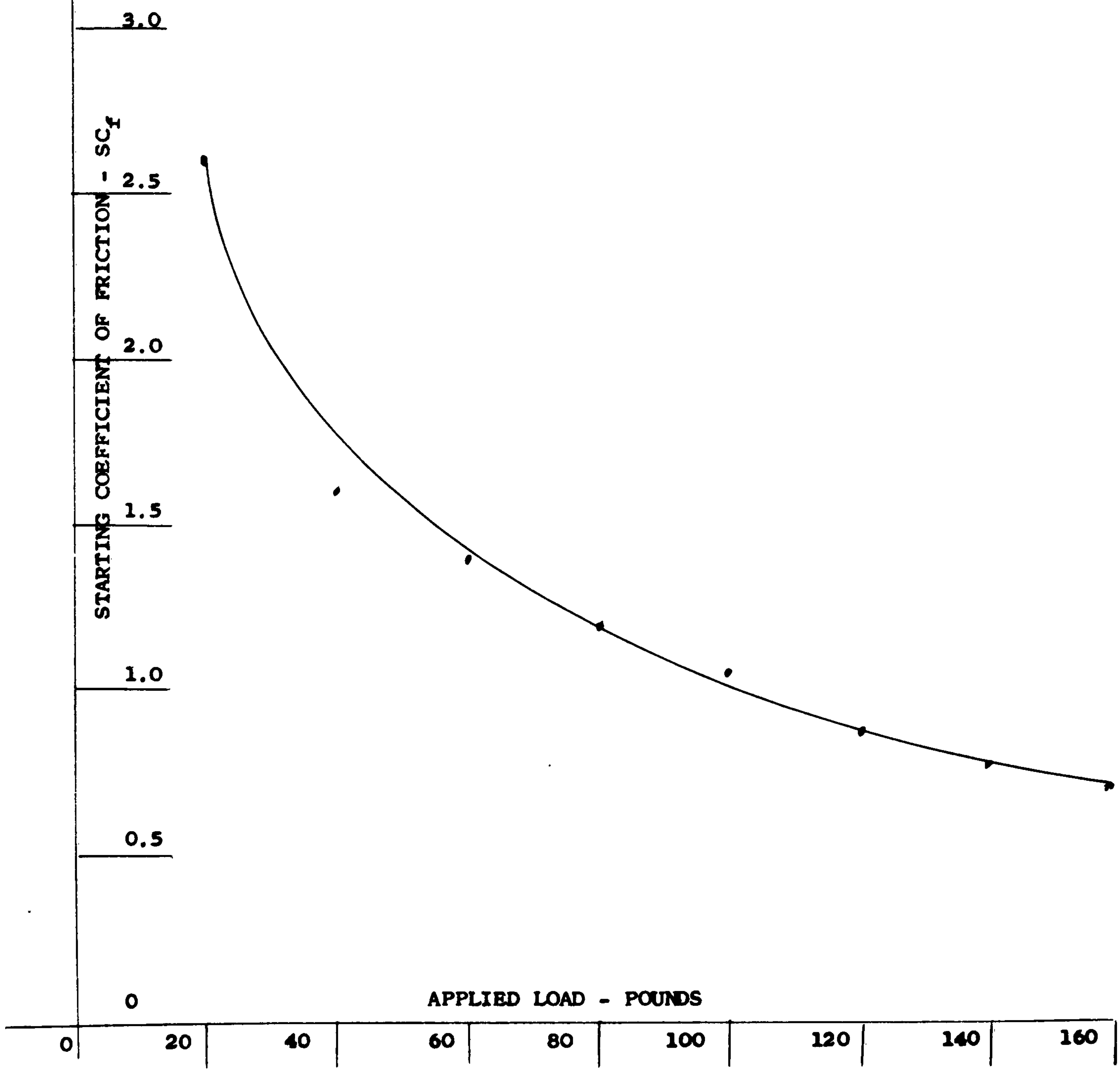


Figure 22

Starting Coefficient of Friction - Evaluation of

Various Rubber Compounds Treated with Quantum "Slippery" Rubber Process

Polymer - Cis 4 Polybutadiene(Naugatuck) Untreated

Compound - NOw-60-0123-C-19-AO

Velocity - 0.30 inches/minute

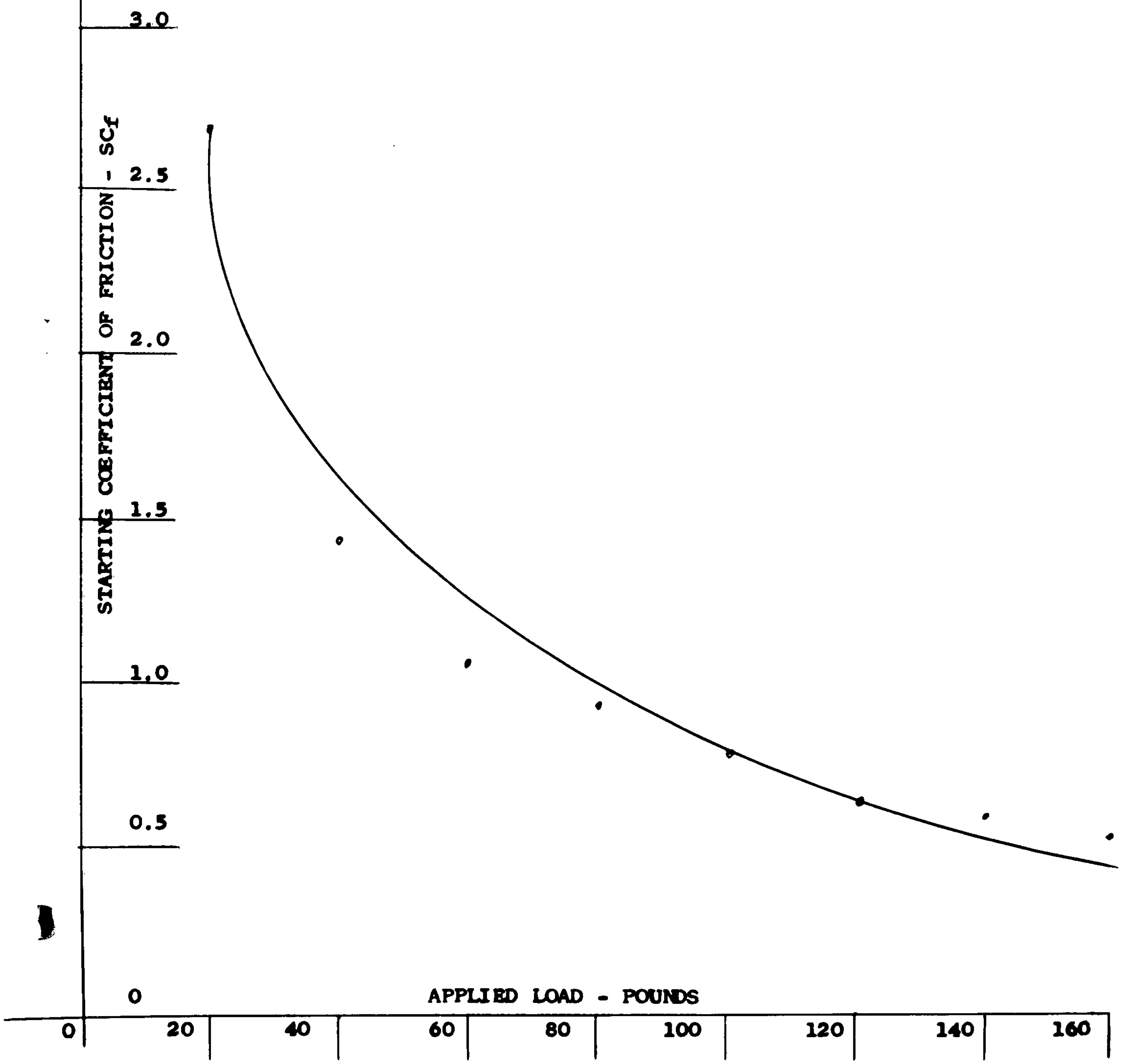


Figure 23

Starting Coefficient of Friction - Evaluation of

Various Rubber Compounds Treated with Quantum "Slippery" Rubber Process

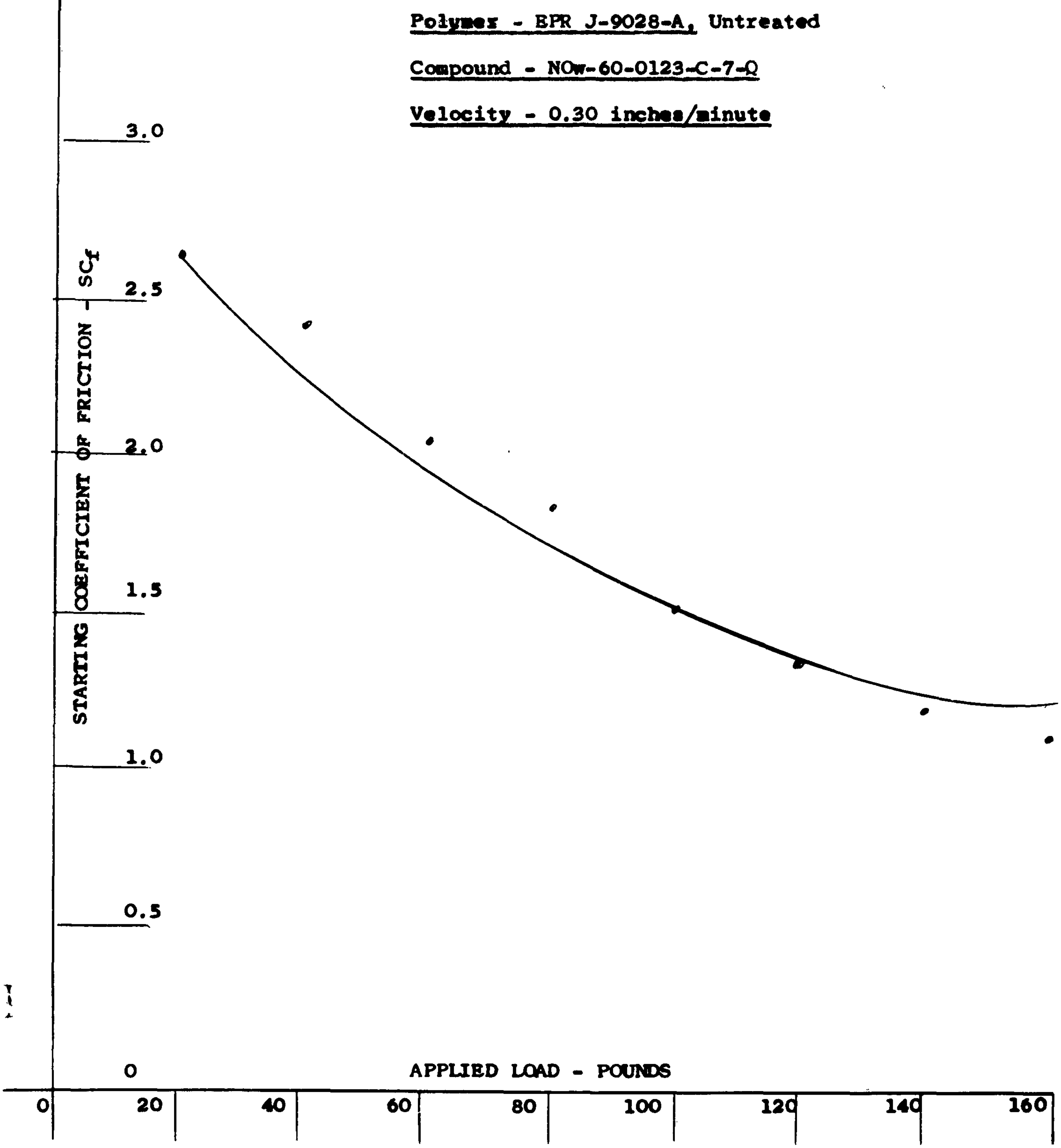


Figure 24

Starting Coefficient of Friction - Evaluation of

Various Rubber Compounds Treated with Quantum "Slippery" Rubber Process

Polymer - PARACRIL 18-80, Treated

Compound - NOw-60-0123-C-63-FM

Velocity - 0.30 inches/minute

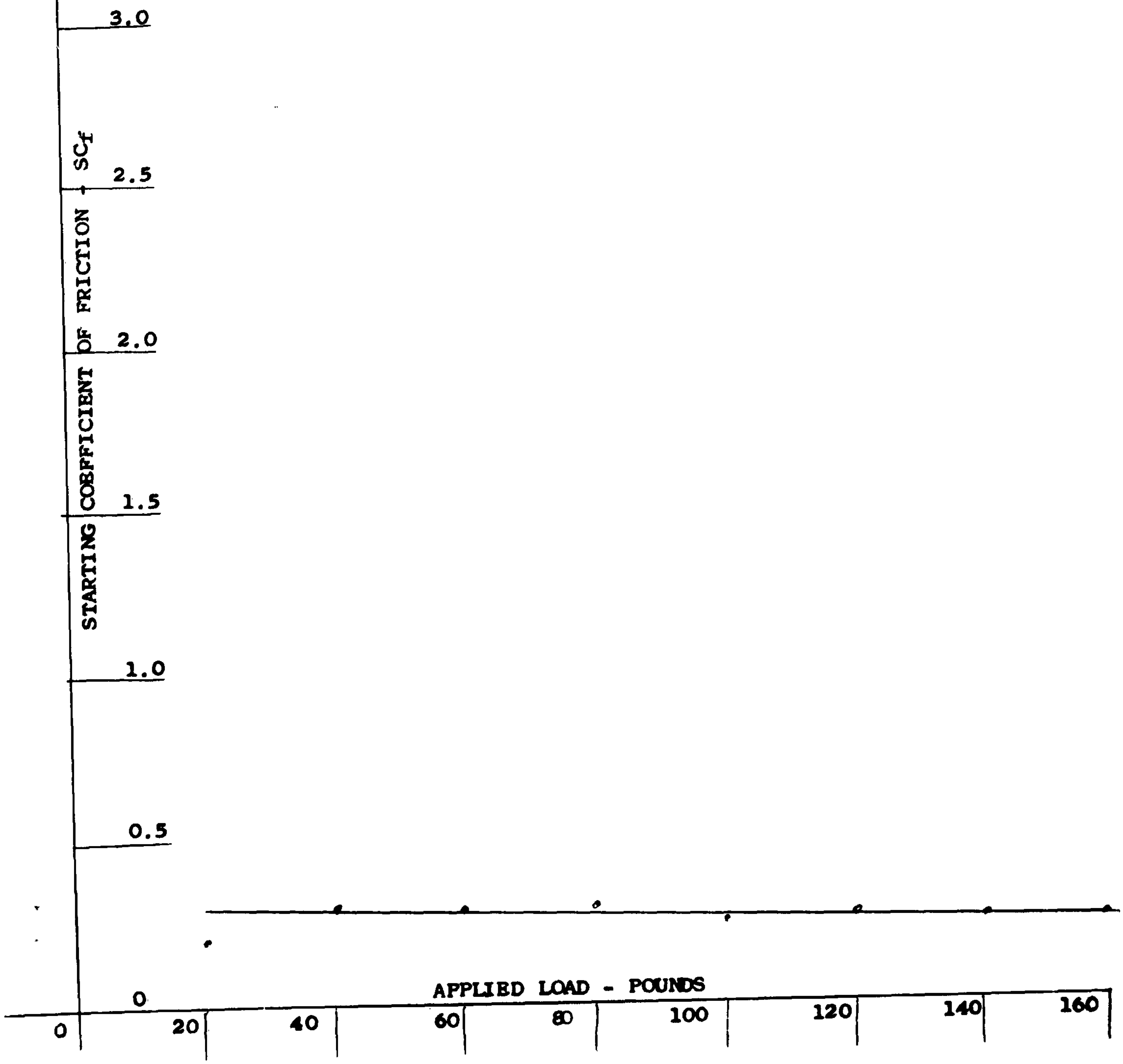


Figure 25

Starting Coefficient of Friction - Evaluation of

Various Rubber Compounds Treated with Quantum "Slippery" Rubber Process

<u>**Polymer - EPR - EP-931, Treated**</u>

<u>**Compound - NOw-60-0123-C-63-FN**</u>

<u>**Velocity - 0.30 inches/minute**</u>

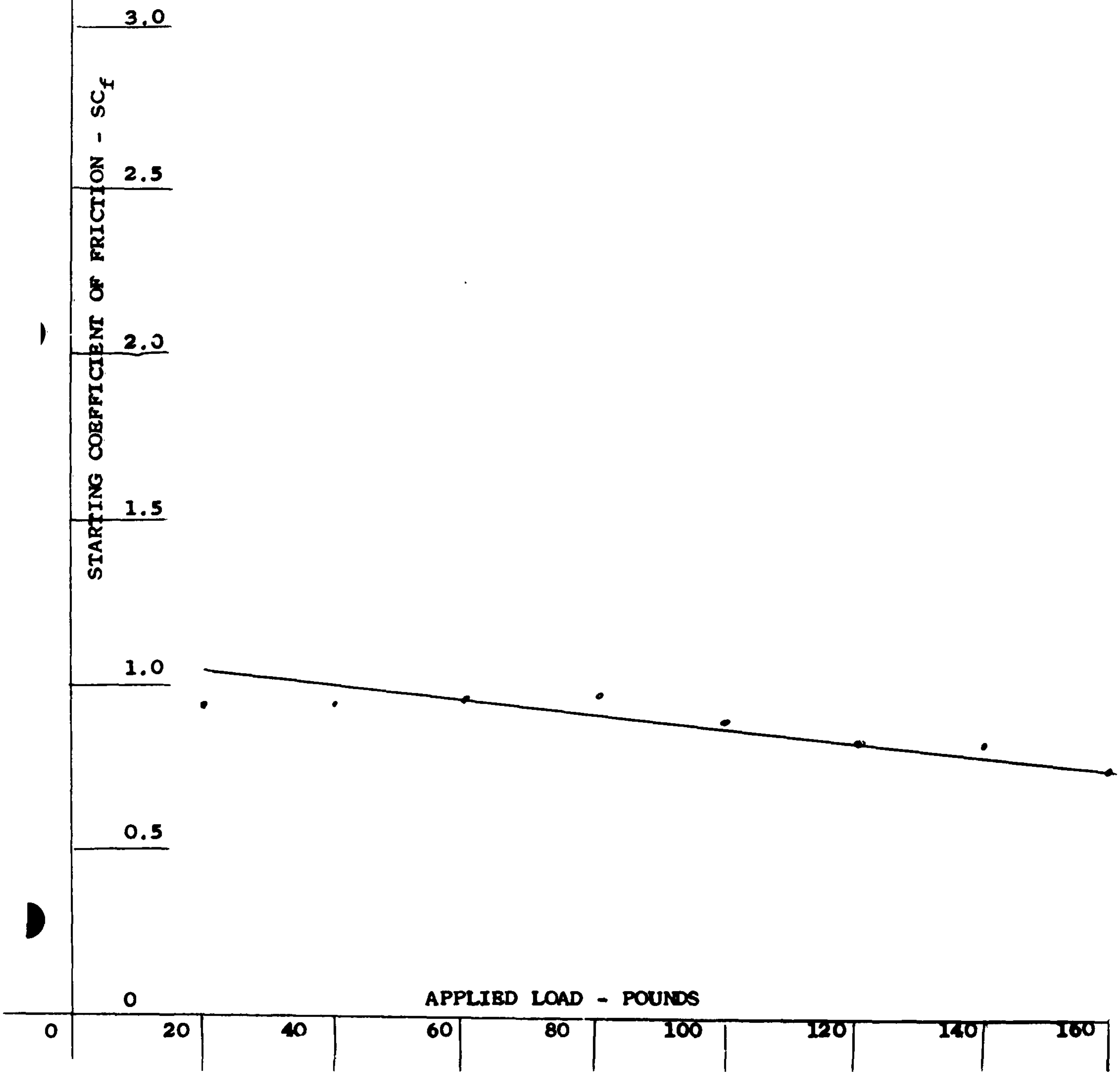


Figure 26

Starting Coefficient of Friction - Evaluation of

Various Rubber Compounds Treated with Quantum "Slippery" Rubber Process

Polymer - NAUGAPOL 1015, Treated

Compound - NOw-60-0123-C-63-FO

Velocity - 0.30 inches/minute

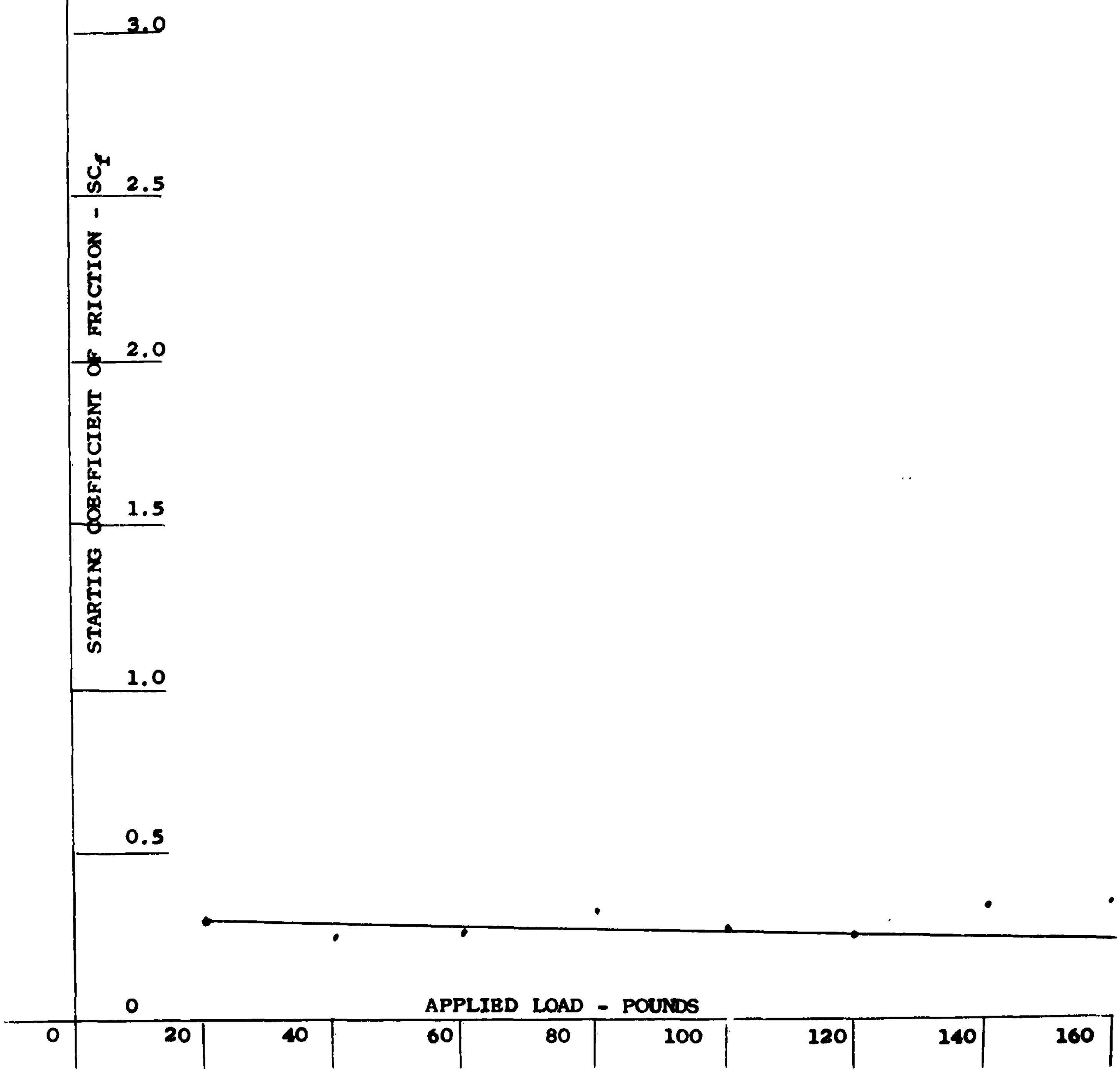


Figure 27

Starting Coefficient of Friction - Evaluation of

Various Rubber Compounds Treated with Quantum "Slippery" Rubber Process

Polymer - Naugatuck Polybutadiene, Treated

Compound - NOw-60-0123-C-63-FP

Velocity - 0.30 inches/minute

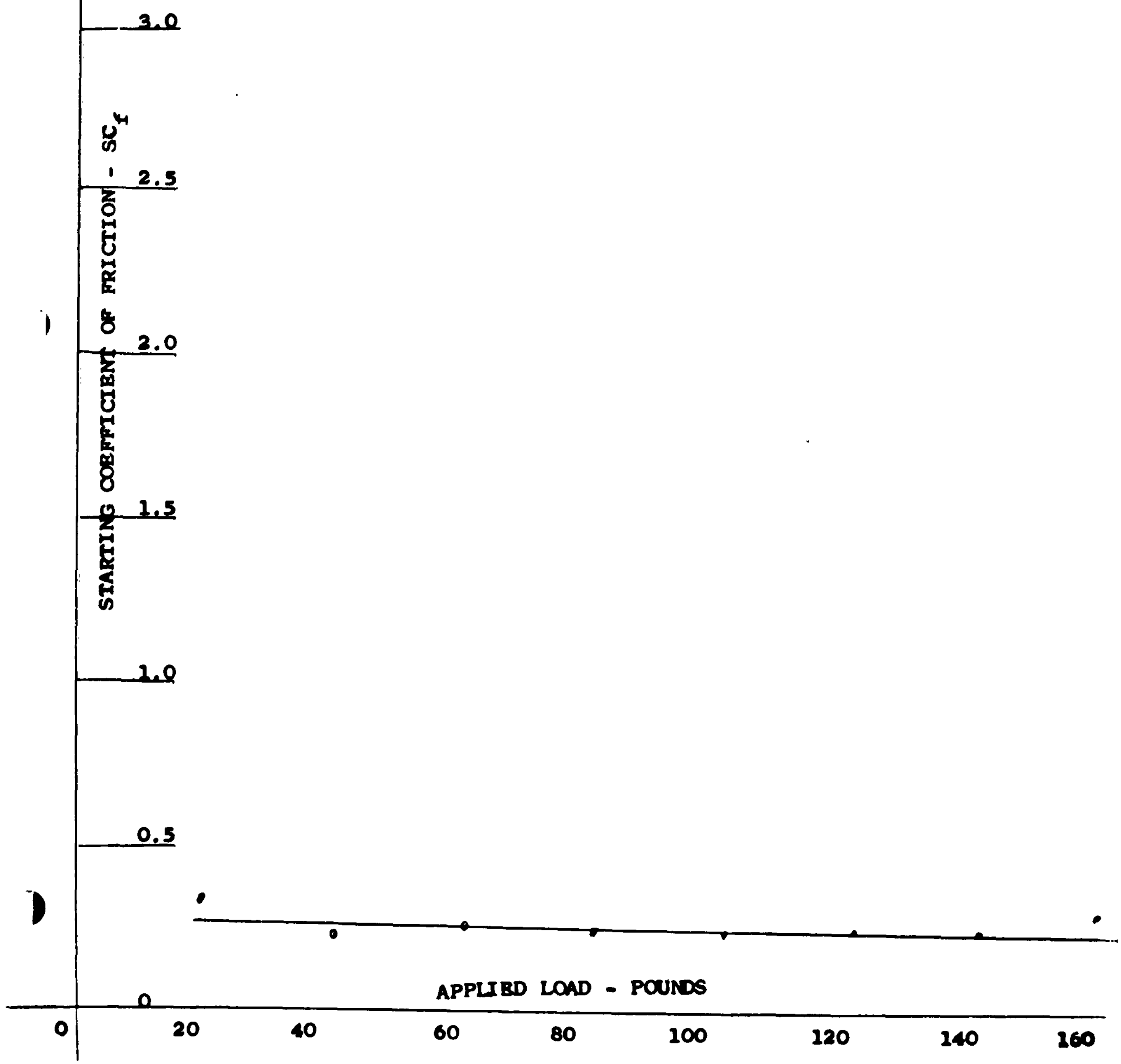


Figure 28

Starting Coefficient of Friction - Evaluation of

Various Rubber Compounds Treated with Quantum "Slippery" Rubber Process

<u>Polymer - EPR-J-9028-A, Treated</u>

<u>Compound - NOw-60-0123-C-63-FQ</u>

<u>Velocity - 0.30 inches/minute</u>

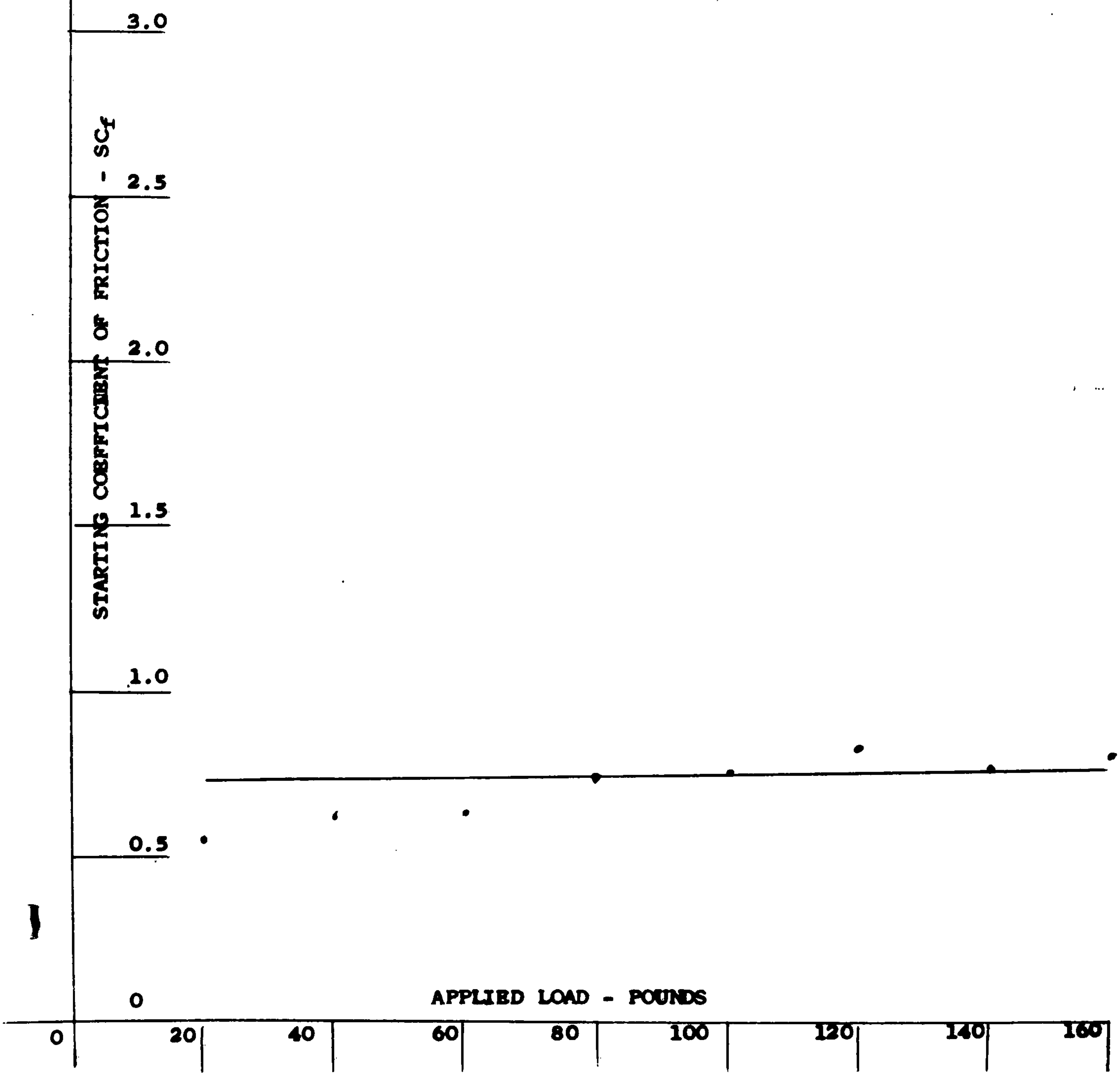


TABLE IX

Starting Coefficient of Friction

Evaluation of Fluorocarbon Resins and Fibers (Teflon) in a Butadiene-Acrylonitrile Compound

NOw-60-0123-C	3-C	43-DL	44-DM
PARACRIL 18-80	100.0	100.0	100.0
Zinc Oxide	10.0	10.0	10.0
AMINOX	2.0	2.0	2.0
Wyex Carbon Black	25.0	25.0	25.0
Pelletex Carbon Black	75.0	75.0	75.0
Paraplex G-25	10.0	10.0	10.0
Plasticizer SC	7.5	7.5	7.5
TP-95 Plasticizer	7.5	7.5	7.5
TUEX	1.5	1.5	1.5
Tetrone A	1.5	1.5	1.5
Teflon Floc	-	25.0	-
Teflon 7 Resin	-	-	25.0
	240.0	265.0	265.0

Cure - 30 minutes at 310°F

Test Velocity - 0.30 inches/minute

Applied Load - Pounds	FF	SC_f	FF	SC_f	FF	SC_f
20	42	2.10	31	1.55	28	1.40
40	62	1.55	50	1.25	44	1.10
60	72	1.20	67	1.12	64	1.07
80	85	1.06	73	0.91	75	0.94
100	98	0.98	86	0.86	84	0.84
120	95	0.79	99	0.83	90	0.75
140	107	0.76	101	0.72	102	0.73
160	113	0.71	111	0.69	120	0.75

Original Physical Properties - Cure 30 minutes at 310°F

Modulus 100% psi	700	800	1270
Tensile, psi	1860	1690	1840
Elongation, %	200	180	130
Shore "A" Hardness	69	77	82

Figure 29

Starting Coefficient of Friction - Evaluation of

Fluorocarbon Resins and Fibers (Teflon) in a Butadiene-Acrylonitrile Compound

Polymer - PARACRIL 18-80

Compound - NOw-60-0123-C-3-C

Velocity - 0.30 inches/minute

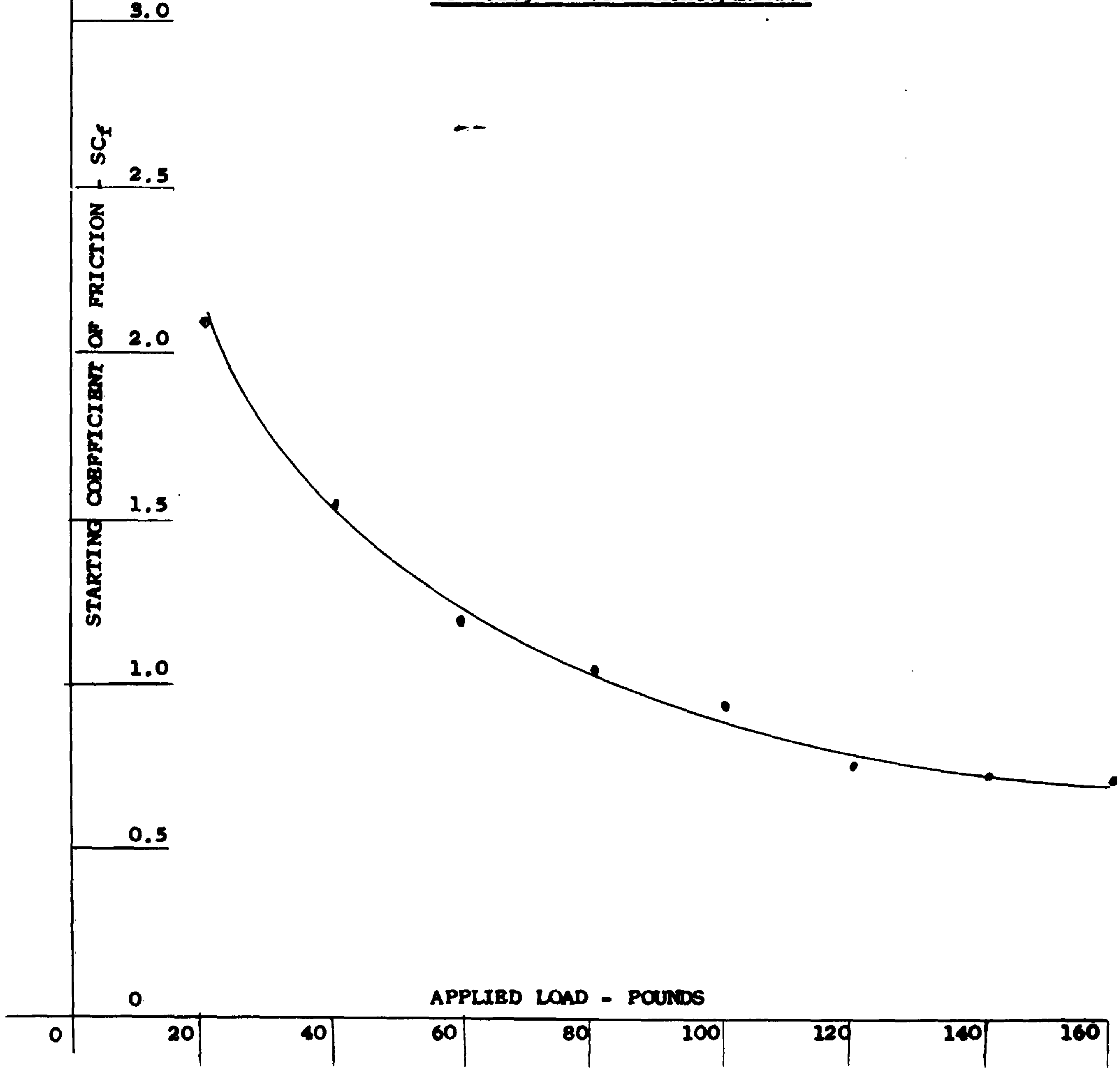


Figure 30

Starting Coefficient of Friction - Evaluation of

Fluorocarbon Resins and Fibers (Teflon) in a Butadiene-Acrylonitrile Compound

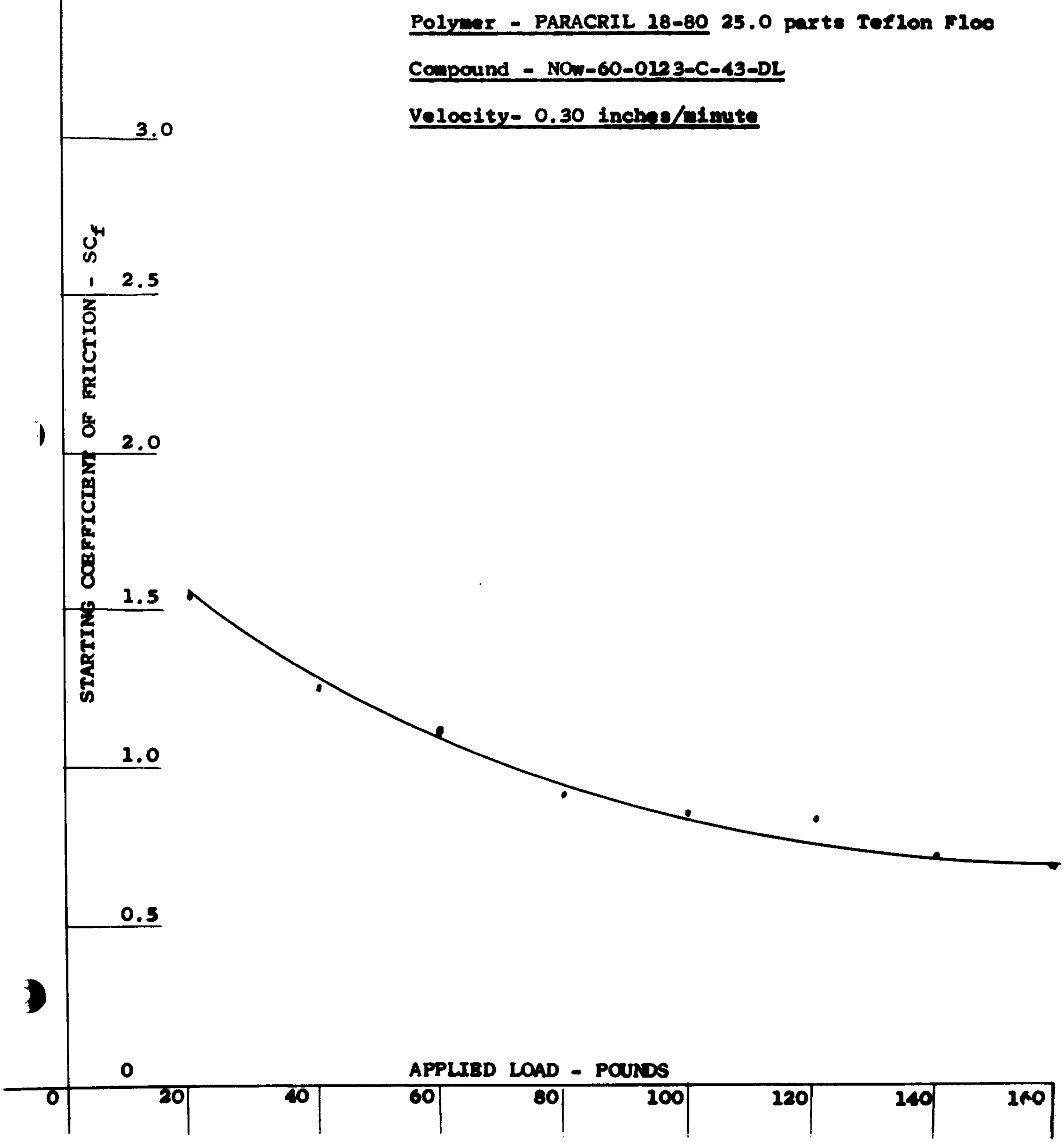


Figure 31

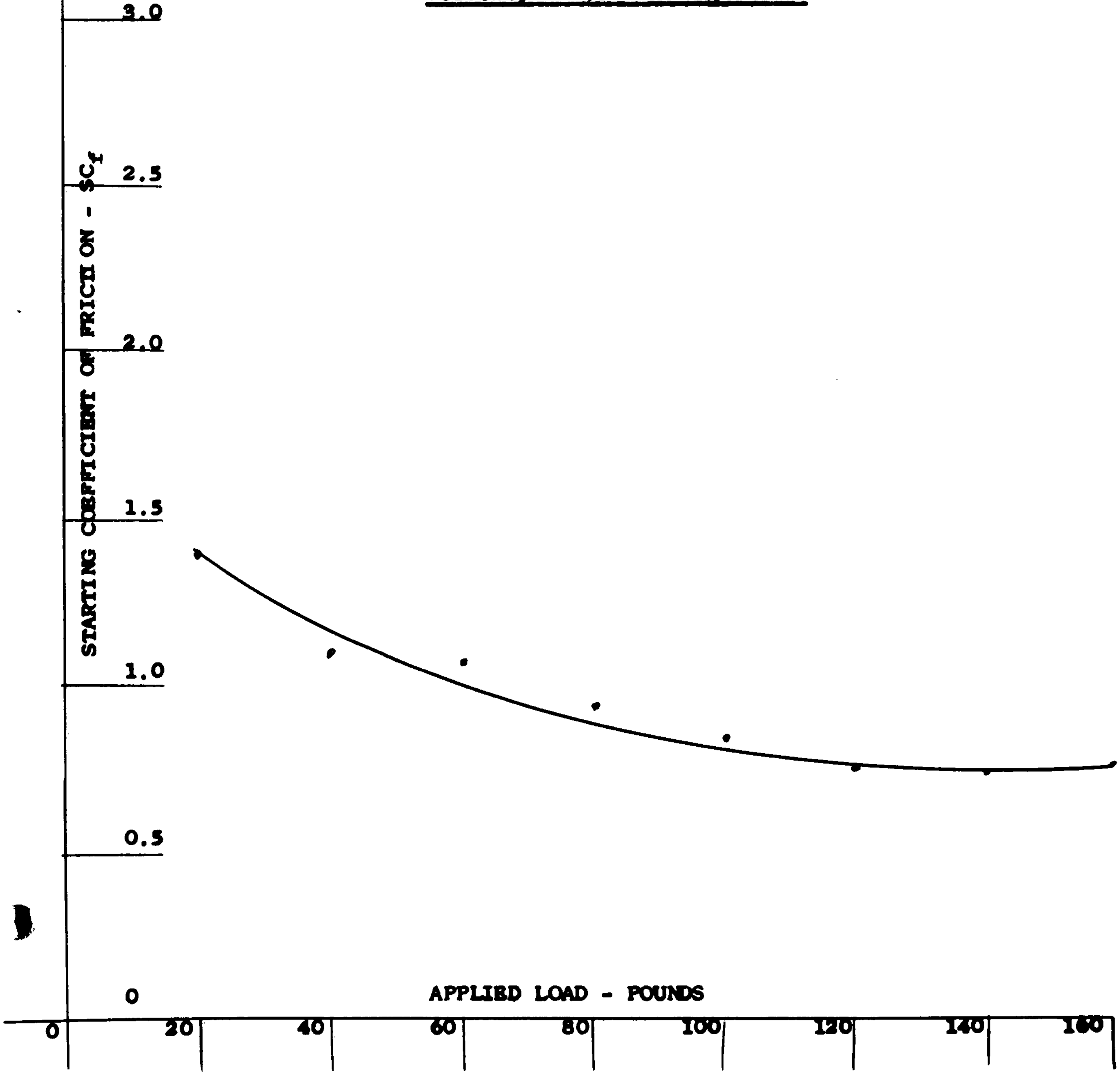
Starting Coefficient of Friction - Evaluation of

Fluorocarbon Resins and Fibers (Teflon) in a Butadiene-Acrylonitrile Compound

<u>Polymer - PARACRIL 18-80</u> 25.0 parts Teflon 7 Resin

<u>Compound - NOw-60-0123-C-44-DM</u>

<u>Velocity - 0.30 inches/minute</u>



T A B L E X

Starting Coefficient of Friction

Evaluation of Fluorocarbon Resin, Wax and Oil in Butadiene-Acrylonitrile Rubber Compounds

NOw-60-0123-C	3-C	47-DR	48-DS	49-DT
PARACRIL 18-80	100.0	100.0	100.0	100.0
Zinc Oxide	10.0	10.0	10.0	10.0
AMINOX	2.0	2.0	2.0	2.0
Wyex Carbon Black	25.0	25.0	25.0	25.0
Pelletex Carbon Black	75.0	75.0	75.0	75.0
Paraplex G-25	10.0	10.0	10.0	10.0
Plasticizer SC	7.5	7.5	7.5	7.5
TP-95 Plasticizer	7.5	7.5	7.5	7.5
TUEX	1.5	1.5	1.5	1.5
Tetrone A	1.5	1.5	1.5	1.5
Kel F Resin 300	-	25.0	-	-
Kel F Wax 200	-	-	2.0	-
Kel F Oil 10	-	-	-	5.0
	240.0	265.0	242.0	245.0

Cure - 30 minutes at 310°F

Test Velocity - 0.30 inches/minute

Applied Load-Pounds	FF	SC_f	FF	SC_f	FF	SC_f	FF	SC_f
20	42	2.10	36	1.80	38	1.90	32	1.60
40	62	1.55	60	1.50	55	1.38	54	1.35
60	72	1.20	75	1.25	70	1.17	72	1.20
80	85	1.06	79	0.99	82	1.03	83	1.04
100	98	0.98	93	0.93	96	0.96	94	0.94
120	95	0.79	108	0.90	105	0.88	106	0.88
140	107	0.76	117	0.84	115	0.82	119	0.85
160	113	0.71	126	0.79	117	0.73	125	0.78

Original Physical Properties - Cured 30 minutes at 310°F

Modulus at 100%,psi	700	700	750	660
Tensile, psi	1860	1300	1750	1810
Elongation, %	200	150	180	200
Shore "A" Hardness	69 69	70	66	63

Figure 32

Starting Coefficient of Friction - Evaluation of Fluorocarbon Resins, Wax and Oil in a Butadiene - Acrylonitrile Compound

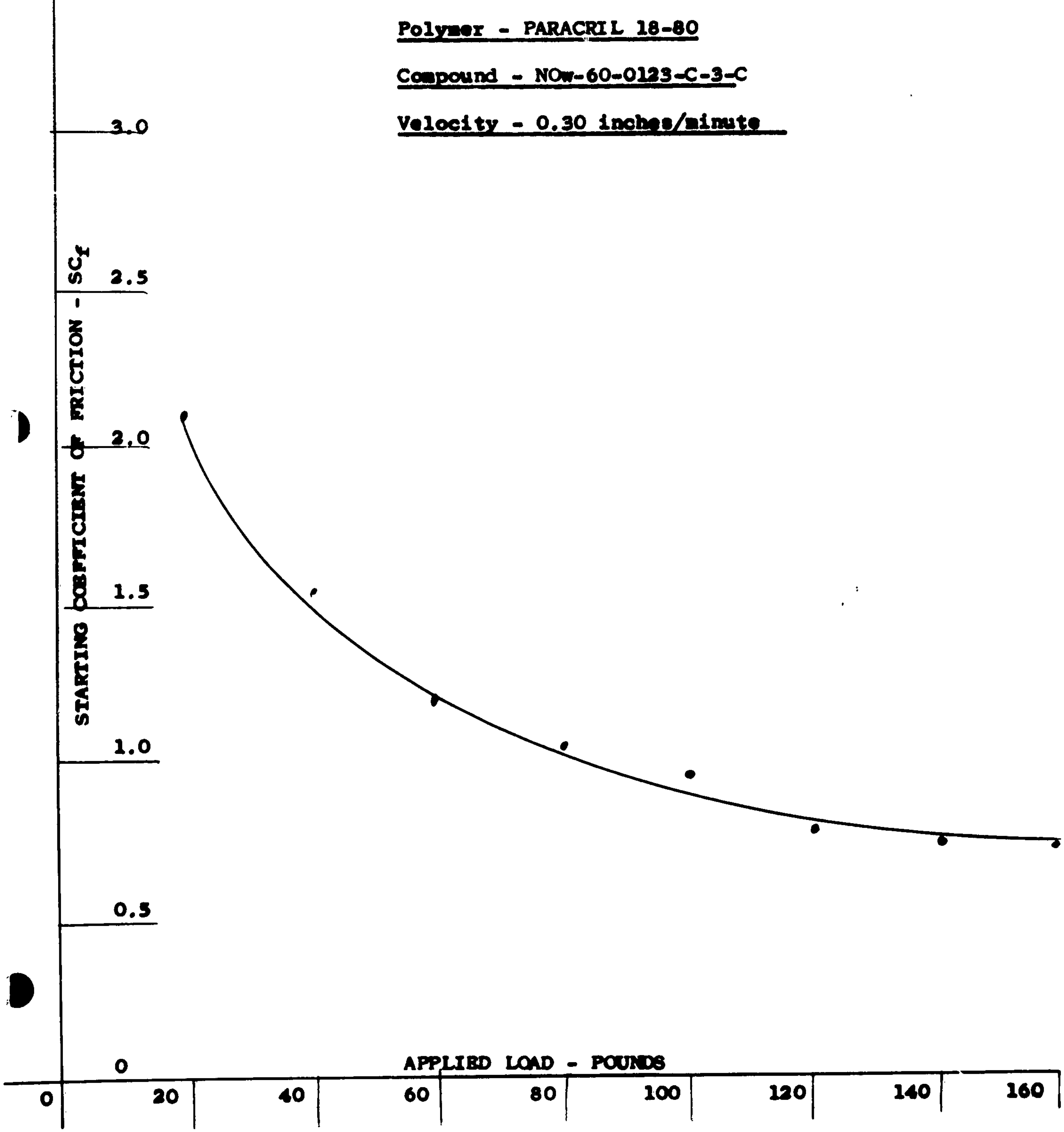


Figure 33

Starting Coefficient of Friction - Evaluation of

Fluorocarbon Resins Wax and Oil in Butadiene-Acrylonitrile Rubber Compounds

<u>Polymer - PARACRIL 18-80</u> - 25.0 parts Kel F Resin 300

<u>Compound - NOw-60-0123-C-47-DR</u>

<u>Velocity - 0.30 inches/minute</u>

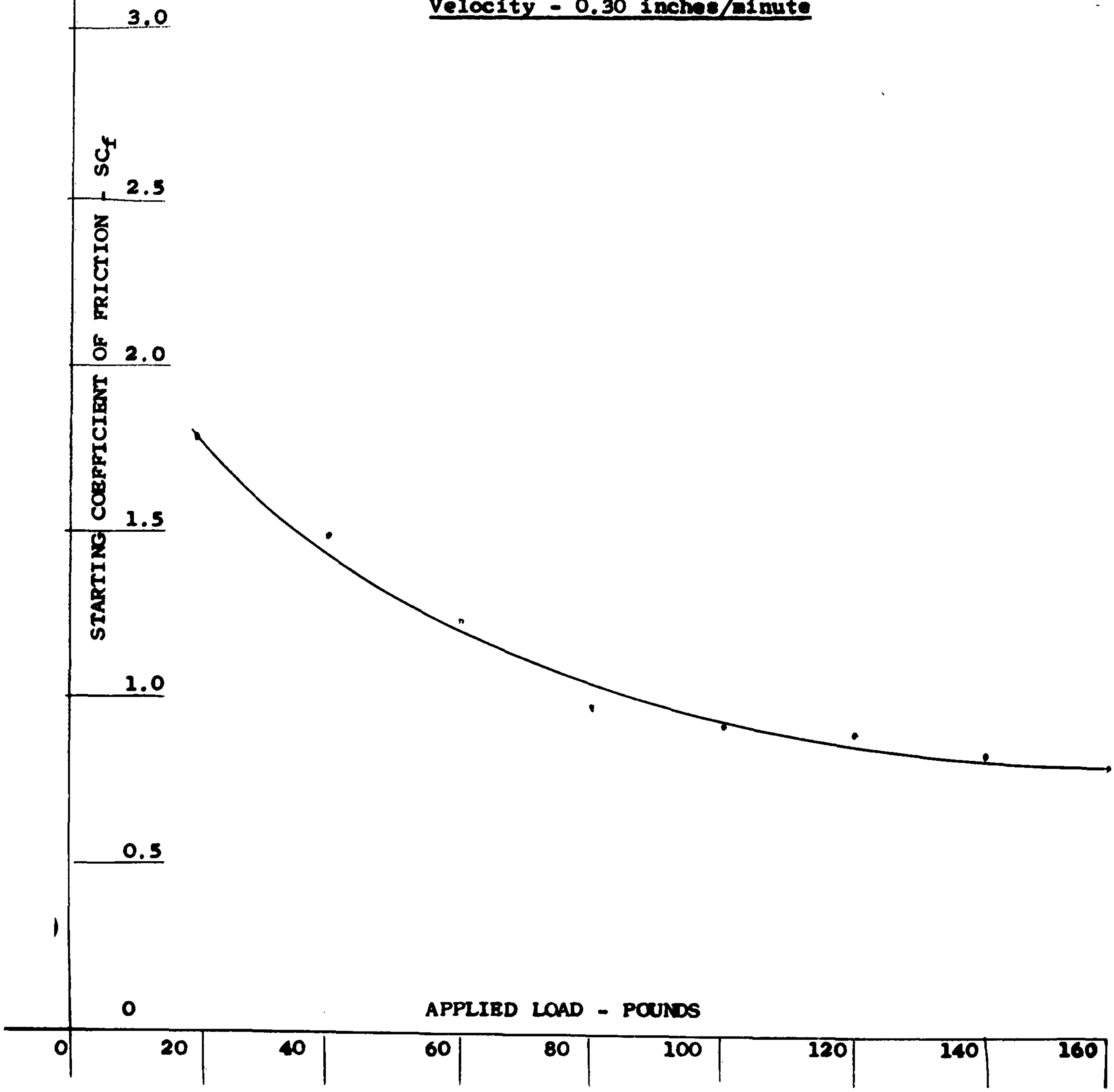


Figure 34

Starting Coefficient of Friction - Evaluation of

Fluorocarbon Resin, Wax and Oil in Butadiene-Acrylonitrile Rubber Compounds

Polymer - PARACRIL 18-80 2.0 parts Kel Wax - Grade 200

Compound - NOw-60-0123-C-48-DS

Velocity - 0.30 inches/minute

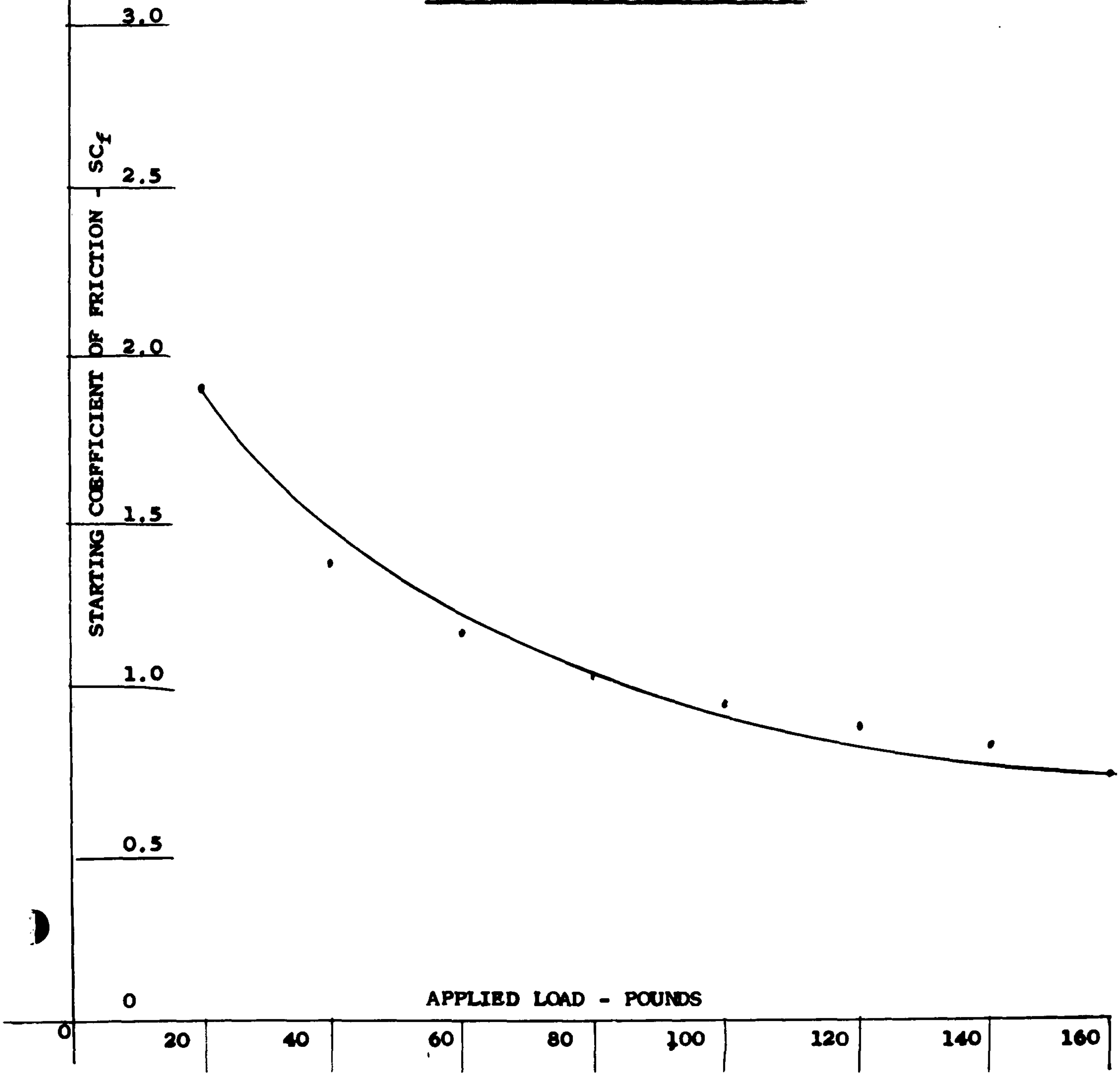


Figure 35

Starting Coefficient of Friction - Evaluation of

Fluorocarbon Resins, Wax and Oil in Butadiene-Acrylonitrile Rubber Compounds

Polymer - PARACRIL 18-80 5.0 parts Kel F Oil #10

Compound - NOw-60-0123-C-49-DT

Velocity - 0.30 inches/minute

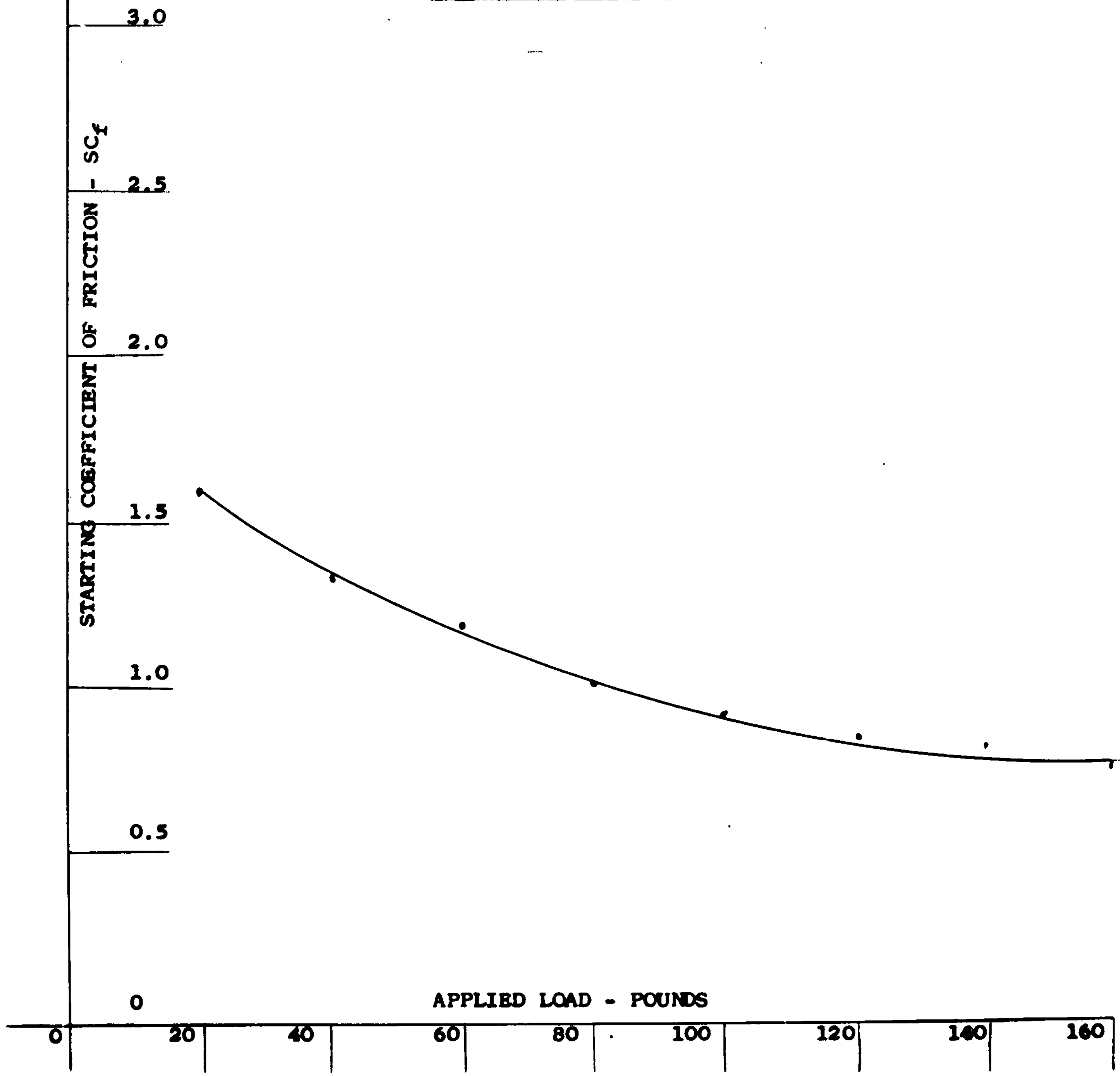


TABLE XI

Starting Coefficient of Friction

Evaluation of Fluorocarbon Telomers and Dispersions in a

Butadiene-Acrylonitrile Rubber Compound

NOw-60-0123-C	3-C	54-EK	54-EL
PARACRIL 18-80	100.0	100.0	100.0
Zinc Oxide	10.0	10.0	10.0
AMINOX	2.0	2.0	2.0
Wyex Carbon Black	25.0	25.0	25.0
Pelletex Carbon Black	75.0	75.0	75.0
Paraplex G-25	10.0	10.0	10.0
Plasticizer SC	7.5	7.5	7.5
TP-95 Plasticizer	7.5	7.5	7.5
TUEX	1.5	1.5	1.5
Vydax A	-	1.0	-
TLT-111	-	-	1.0
	240.0	241.0	241.0

Cure - 30 minutes at 310°F

Test Velocity - 0.30 inches/minute

Applied Load - Pounds	FF	SC_f	FF	SC_f	FF	SC_f
20	42	2.10	40	2.00	42	2.10
40	62	1.55	61	1.53	63	1.58
60	72	1.20	80	1.33	73	1.22
80	85	1.06	88	1.10	88	1.10
100	98	0.98	99	0.99	94	0.94
120	95	0.79	108	0.90	98	0.82
140	107	0.76	113	0.81	114	0.81
160	113	0.71	127	0.79	120	0.75

Original Physical Properties - Cured 30 minutes at 310°F

Modulus at 100%, psi	930	880	930
Tensile, psi	2080	1970	1860
Elongation, %	170	170	170
Shore "A" Hardness	67	70	68

Figure 36

Starting Coefficient of Friction - Evaluation of Fluorocarbon Telomers and Dispersions in a Butadiene-Acrylonitrile Rubber Compound

Polymer - PARACRIL 18-80

Compound - NOw-60-0123-C-3-C

Velocity - 0.30 inches/minute

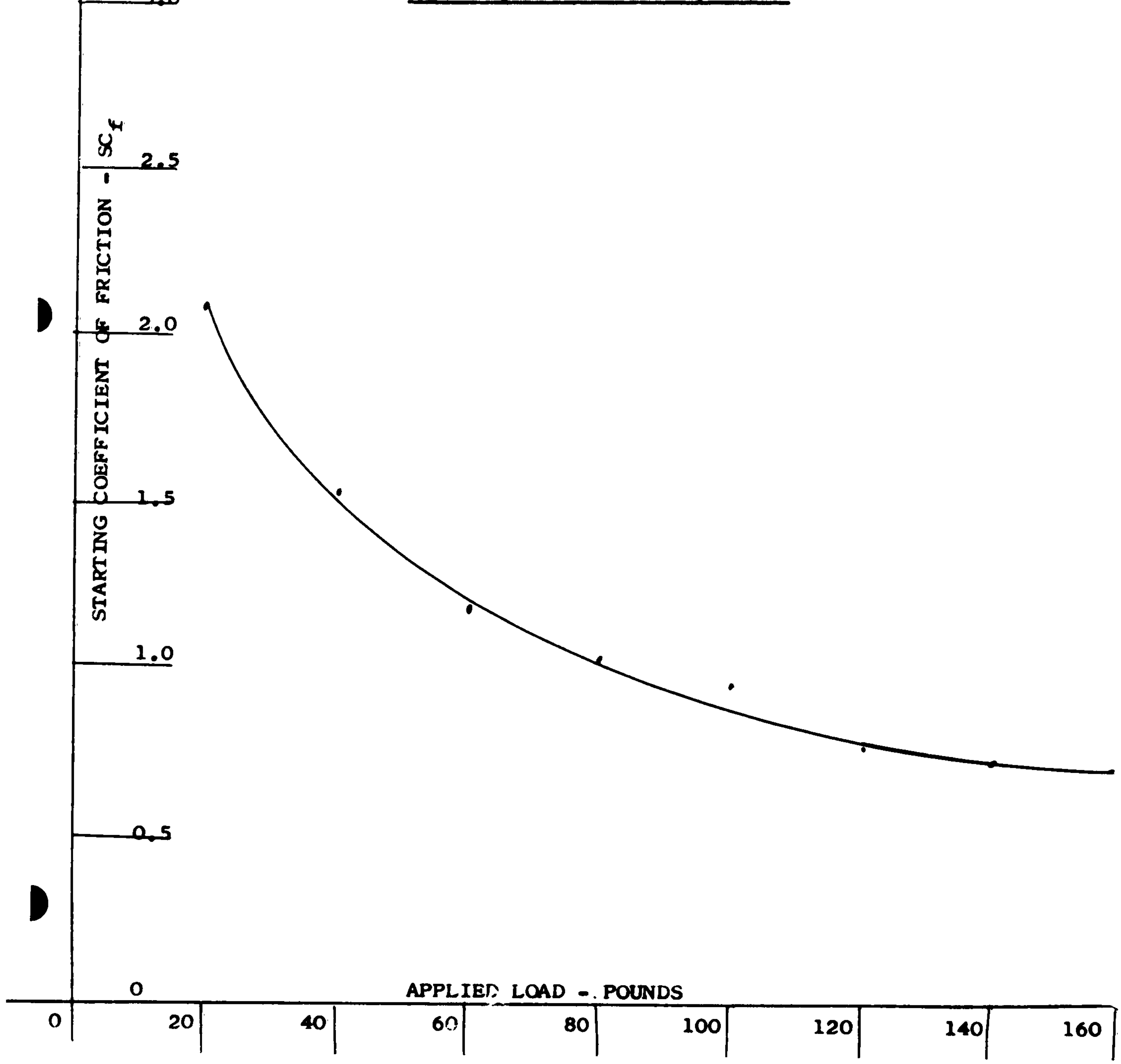


Figure 37

Starting Coefficient of Friction - Evaluation of Fluorocarbon Telomers and Dispersions in a Butadiene-Acrylonitrile Rubber Compound

Polymer - PARACRIL 18-80

Compound - NOw-60-0123-C-54-EK

Velocity - 0.30 inches/minute

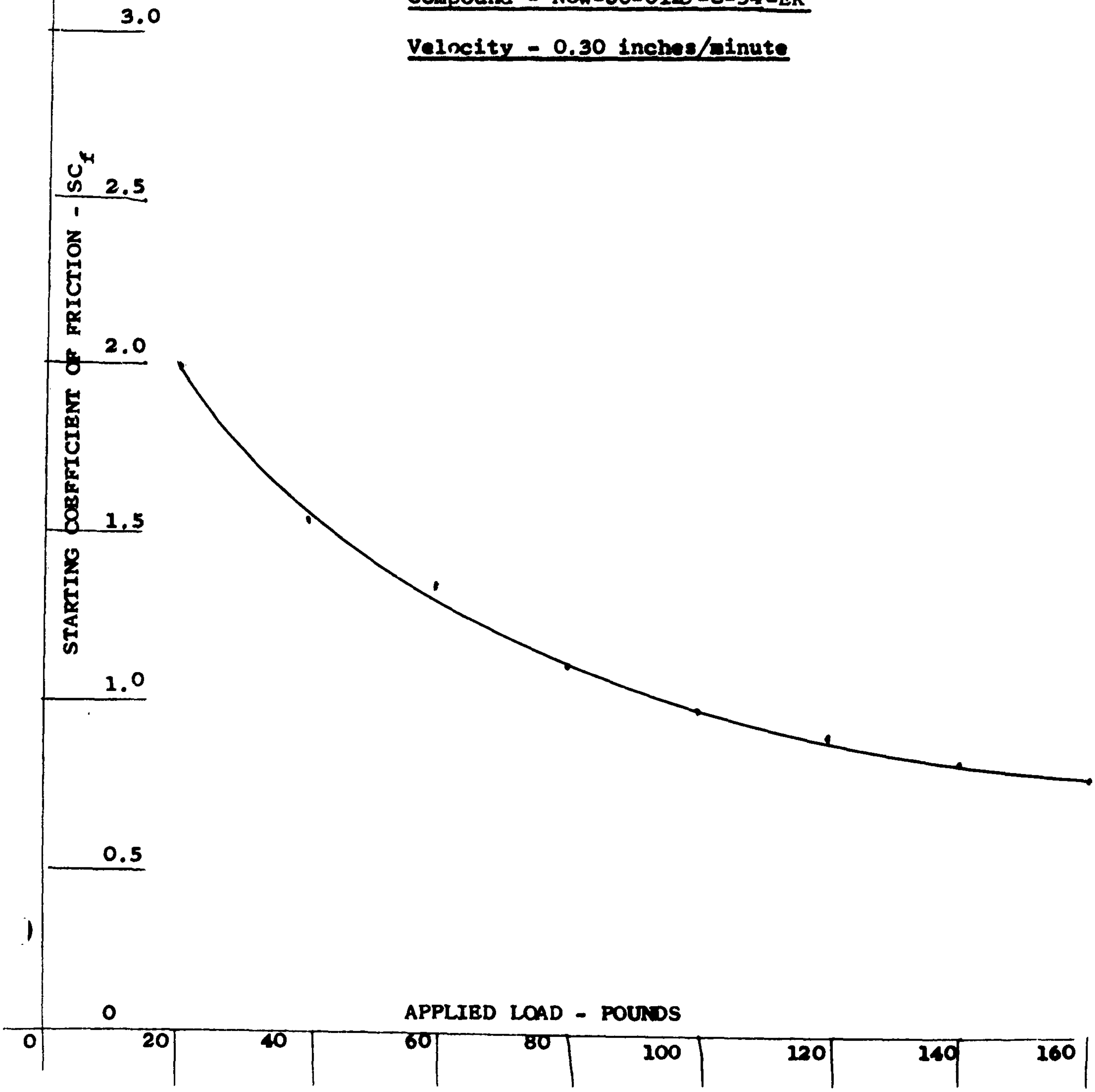
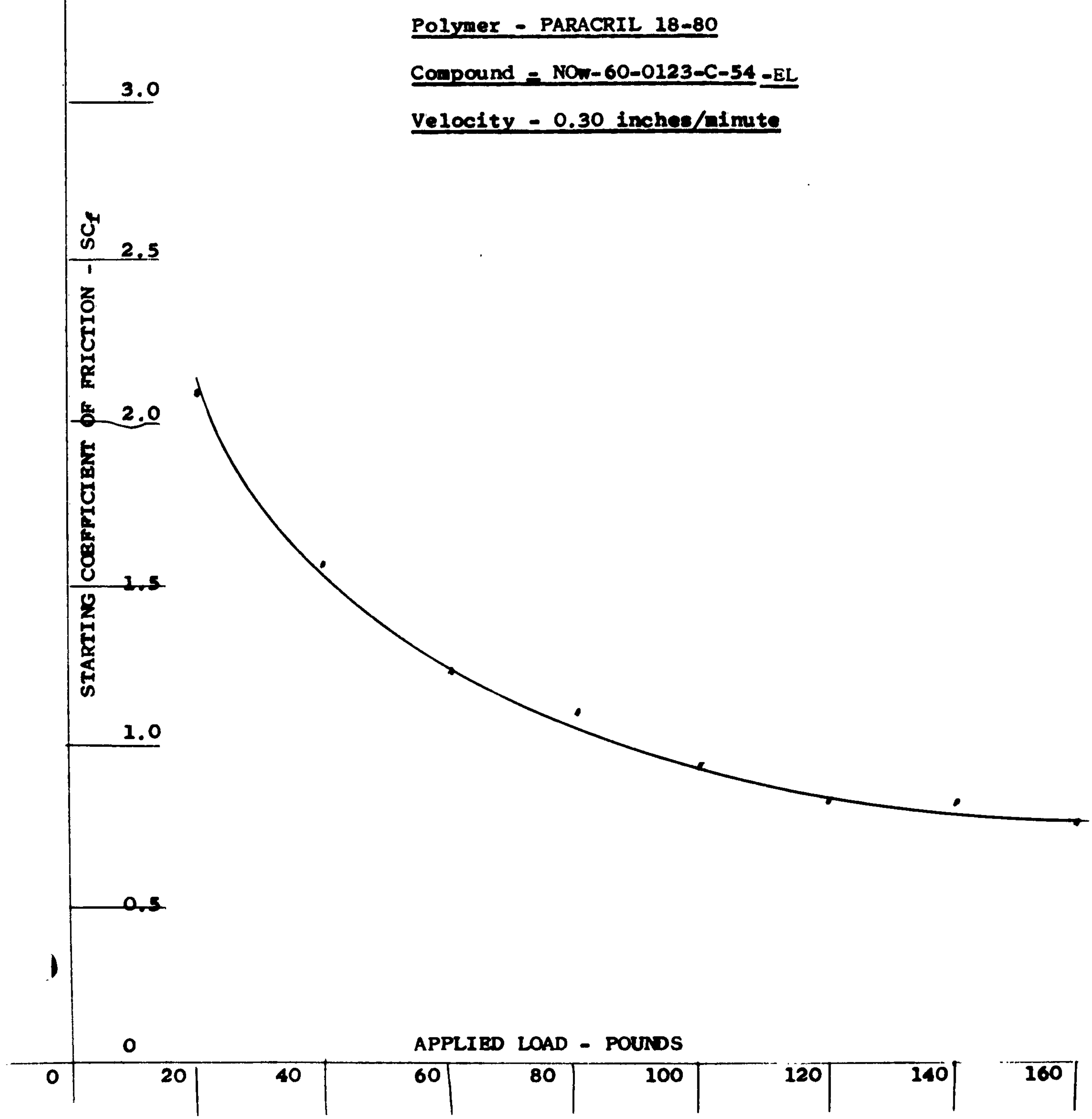


Figure 38

Starting Coefficient of Friction - Evaluation of

Fluorocarbon Telomers and Dispersions in a Butadiene-Acrylonitrile

Rubber Compound



T A B L E   X I I

Starting Coefficient of Friction

Evaluation of Molybdenum Disulfide in a

Butadiene-Acrylonitrile Rubber Compound

NOw-60-0123-C-42	3-C	42-DH	42-DI	42-DJ
PARACRIL 18-80	100.0	100.0	100.0	100.0
Zinc Oxide	10.0	10.0	10.0	10.0
AMINOX	2.0	2.0	2.0	2.0
Wyex Carbon Black	25.0	25.0	25.0	25.0
Pelletex Carbon Blk	75.0	75.0	75.0	75.0
Paraplex G-25	10.0	10.0	10.0	10.0
Plasticizer SC	7.5	7.5	7.5	7.5
TP-95 Plasticizer	7.5	7.5	7.5	7.5
TUEX	1.5	1.5	1.5	1.5
Tetrone A	1.5	1.5	1.5	1.5
Molybdenum Disulfide	-	5.0	10.0	20.0
	240.0	245.0	250.0	260.0

Cure - 30 minutes at 310°F

Test Velocity - 0.30 inches/minute

Applied Load-Pounds	FF	SC_f	FF	SC_f	FF	SC_f	FF	SC_f
20	42	2.10	32	1.60	33	1.65	33	1.65
40	62	1.55	56	1.40	60	1.50	51	1.27
60	72	1.20	74	1.23	74	1.23	73	1.21
80	85	1.06	84	1.05	90	1.12	83	1.03
100	98	0.98	97	0.97	104	1.04	91	0.91
120	95	0.79	106	0.88	113	0.94	101	0.84
140	107	0.76	116	0.83	123	0.88	111	0.79
160	113	0.71	122	0.76	132	0.83	119	0.74

Original Physical Properties - Cure 30 minutes at 310°F

Modulus 100%, psi	560	1000	800	960
Tensile, psi	1840	1650	1930	1800
Elongation, %	300	150	190	160
Shore "A" Hardness	68	70	70	70

Figure 39

Starting Coefficient of Friction - Evaluation of Molybdenum Disulfide in Butadiene Acrylonitrile Rubber Compound

Polymer - PARACRIL 18-80 - 0 parts molybdenum disulfide

Compound - NOw-60-0123-C-3-C

Velocity - 0.30 inches/minute

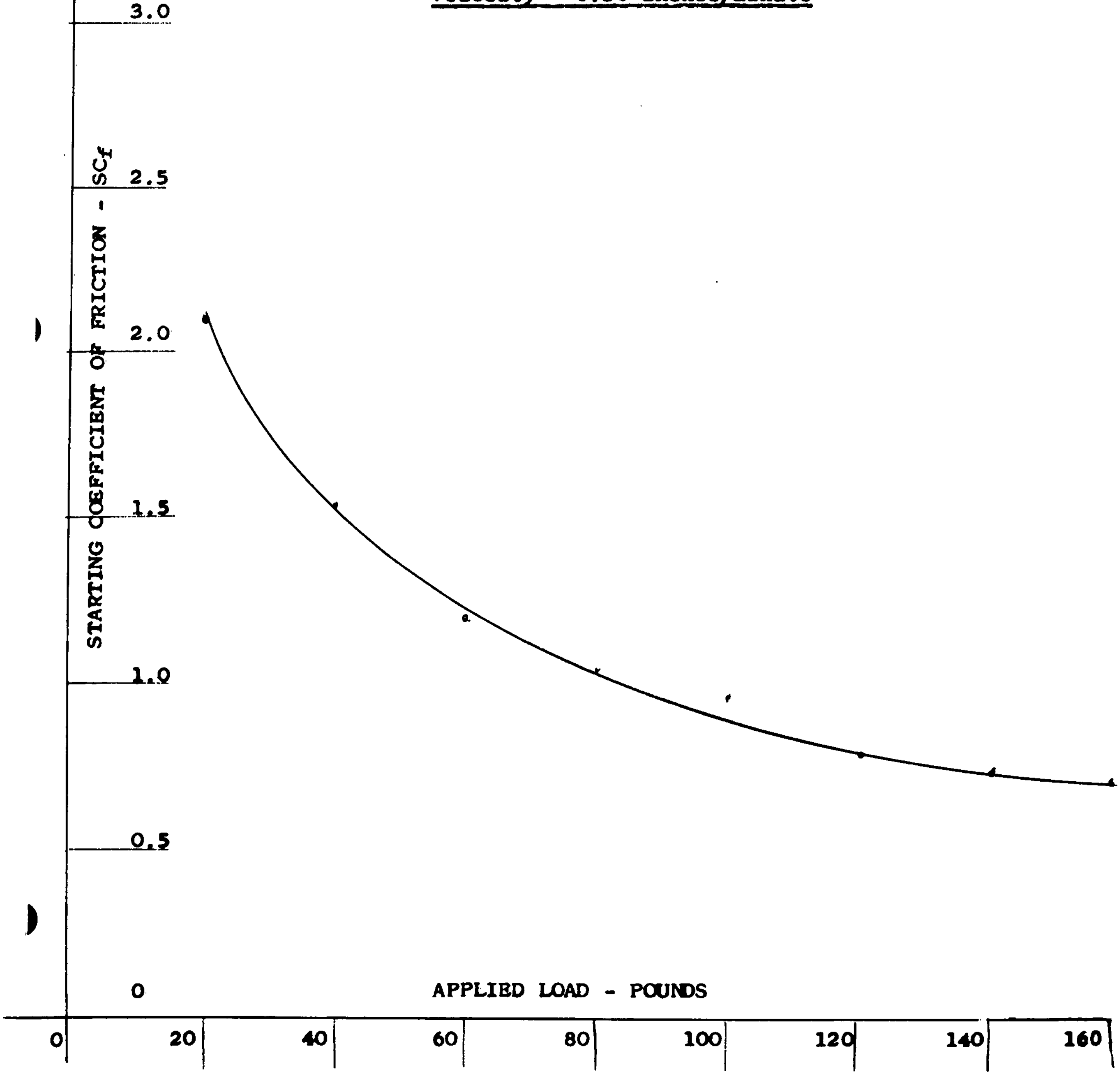


Figure 40

Starting Coefficient of Friction - Evaluation of

Molybdenum Disulfide in Butadiene Acrylonitrile Rubber Compound

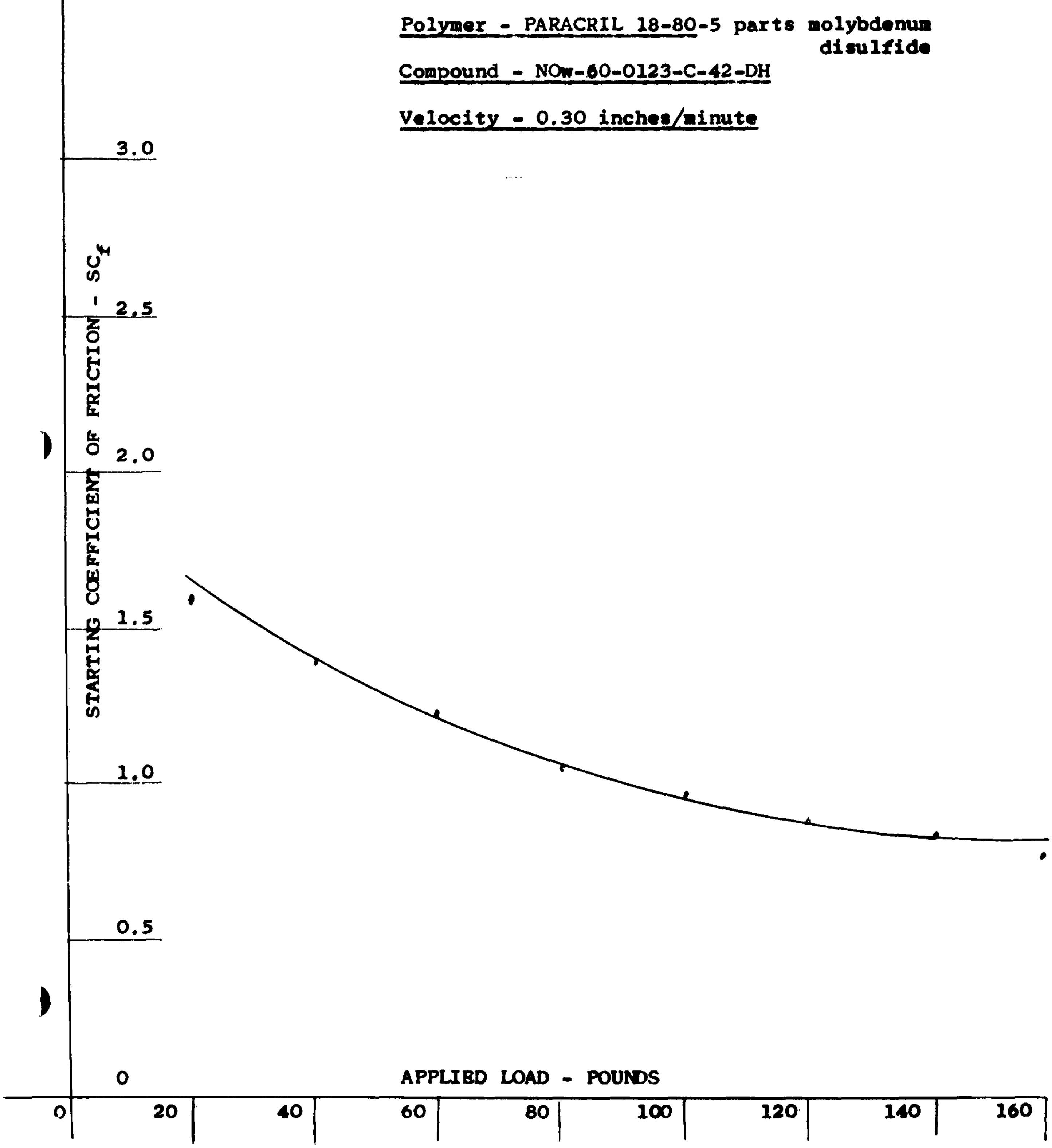


Figure 41

Starting Coefficient of Friction - Evaluation of

Molybdenum Disulfide in Butadiene - Acrylonitrile Rubber Compound

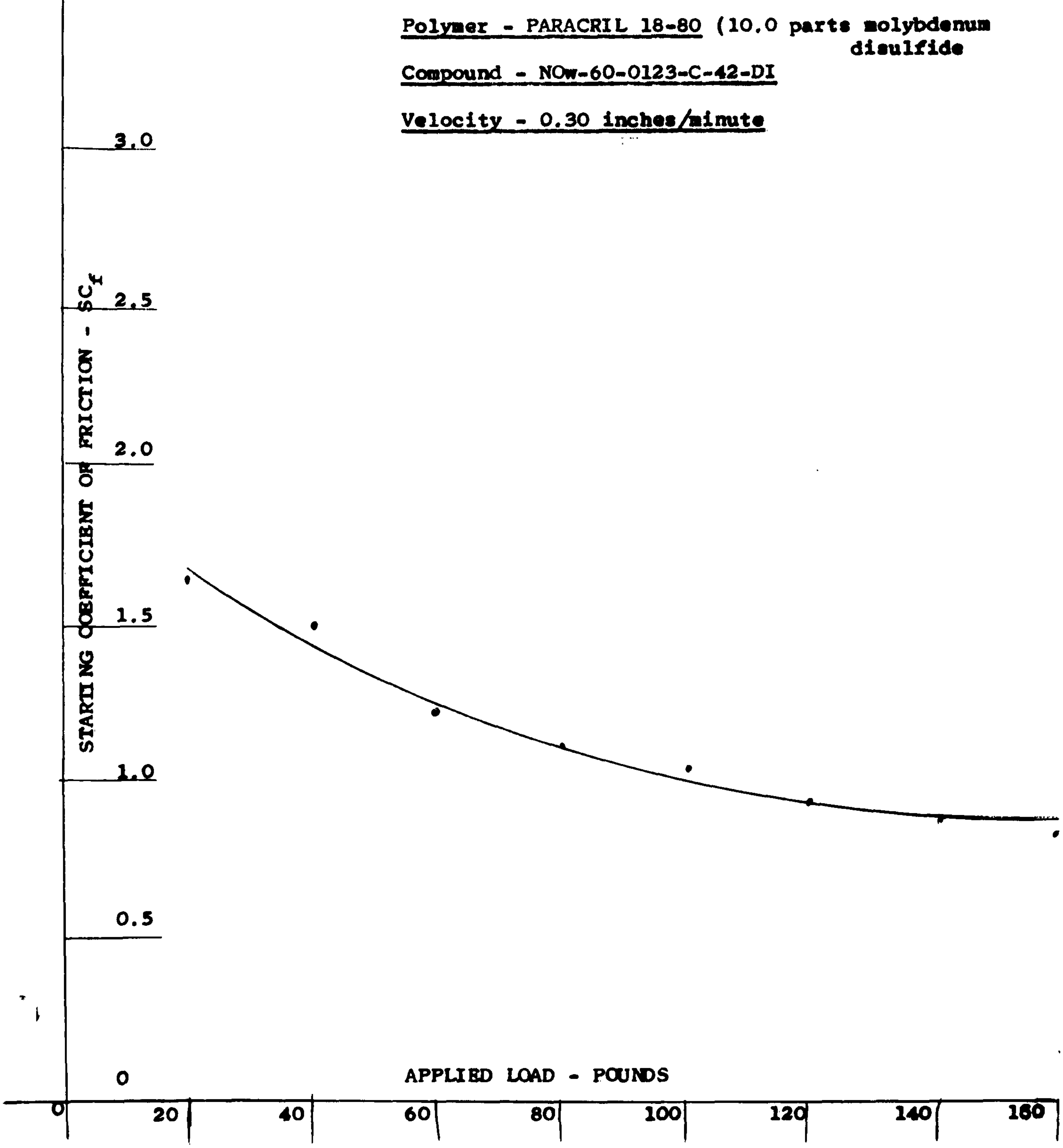


Figure 42

Starting Coefficient of Friction - Evaluation of

Molybdenum Disulfide in Butadiene - Acrylonitrile Rubber Compound

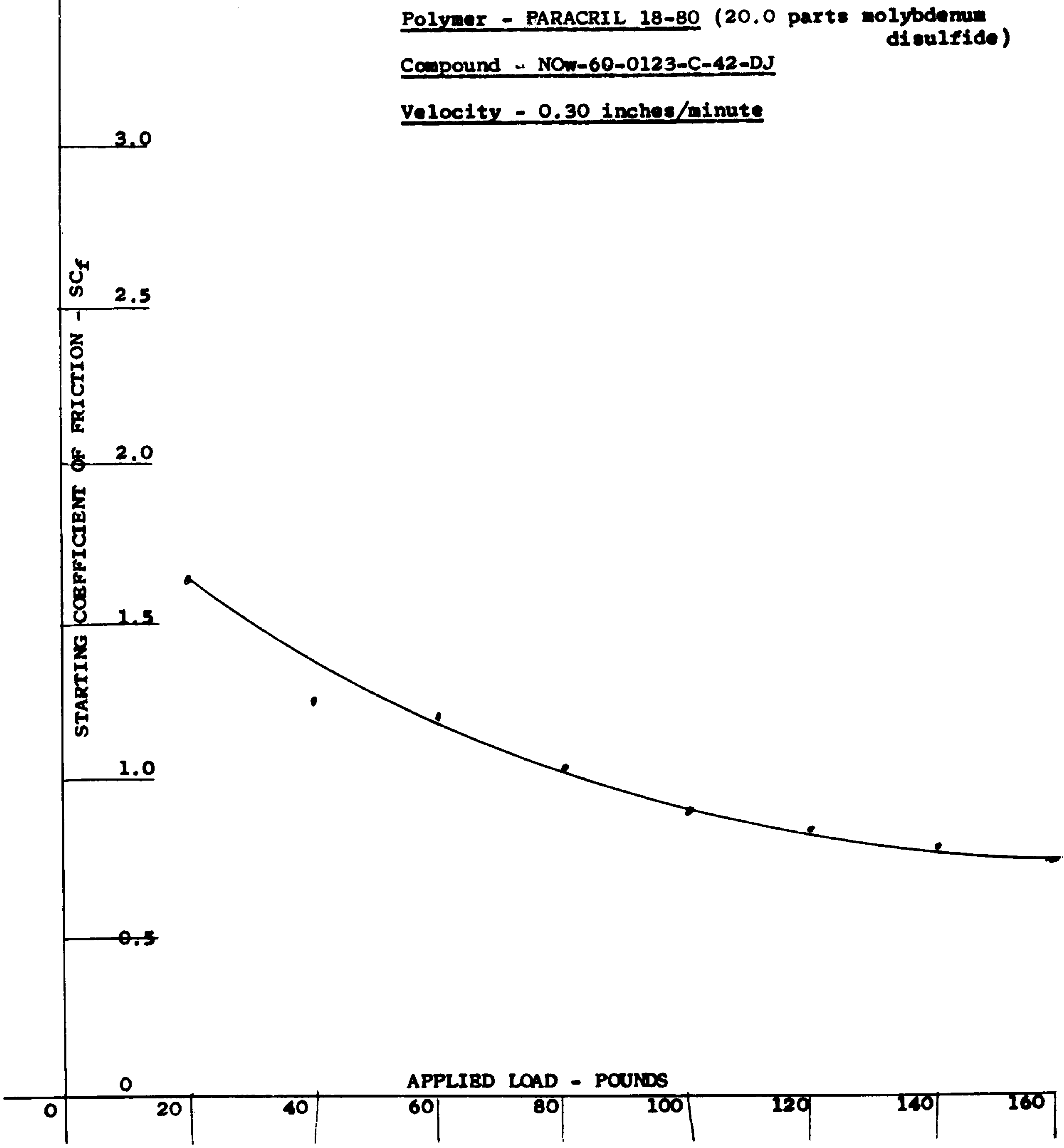


TABLE XIII

Starting Coefficient of Friction

Evaluation of Paraffin Wax Modified with Lithium Stearate in a Butadiene-Acrylonitrile Rubber Compound

NOw-60-0123-C	3-C	53-EF	53-EG	53-EH	53-EI
PARACRIL 18-80	100.0	100.0	100.0	100.0	100.0
Zinc Oxide	10.0	10.0	10.0	10.0	10.0
AMINOX	2.0	2.0	2.0	2.0	2.0
Wyex Carbon Blk	25.0	25.0	25.0	25.0	25.0
Pelletex Carbon Blk	75.0	75.0	75.0	75.0	75.0
Paraplex G-25	10.0	10.0	10.0	10.0	10.0
Plasticizer SC	7.5	7.5	7.5	7.5	7.5
TP-95 Plasticizer	7.5	7.5	7.5	7.5	7.5
TUEX	1.5	1.5	1.5	1.5	1.5
Tetrone A	1.5	1.5	1.5	1.5	1.5
C-29-BP	-	2.0	-	-	-
C-29-BQ	-	-	2.0	-	-
C-29-BR	-	-	-	2.0	-
C-29-BS	-	-	-	-	2.0
	240.0	242.0	242.0	242.0	242.0

Cure - 30 minutes at 310°F

Test Velocity - 0.30 inches/minute

Applied Load Pounds	FF	SC_f	FF	SC_f	FF	SC_f	FF	SC_f	FF	SC_f
20	42	2.10	33	1.65	20	1.00	40	2.00	31	1.55
40	62	1.55	60	1.50	40	1.00	60	1.50	52	1.30
60	72	1.20	75	1.25	60	1.00	77	1.28	70	1.17
80	85	1.06	90	1.13	75	0.94	90	1.13	84	1.05
100	98	0.98	103	1.03	92	0.92	103	1.03	99	0.99
120	95	0.79	107	0.89	100	0.83	113	0.94	110	0.92
140	107	0.76	115	0.82	113	0.81	126	0.90	115	0.82
160	113	0.71	125	0.78	124	0.78	135	0.84	122	0.76

Original Physical Properties - Cure 30 minutes at 310°F

Modulus 100%,psi	560	770	670	750	760
Tensile, psi	1840	1960	1860	1860	1820
Elongation, %	300	200	200	190	200
Shore "A" Hardness	68	66	67	69	66

*Formulations and Procedures for Preparation of Lithium Stearate Modified Paraffin Waxes

NOw-60-0123-C-29	BP	BQ	BR	BS
Paraffin Wax	90.0	80.0	90.0	80.0
Dithium Stearate	10.0	10.0	9.5	9.5
Light Process Oil	-	10.0	-	10.0
DuPont GD162 Phosphated Lauryl Alcohol	-	-	0.5	0.5
	100.0	100.0	100.0	100.0

Mixing instructions for Compound BP

1. Melt paraffin wax and blend in dry lithium stearate
2. Further heat with stirring to the temperature of solution or reaction (around 400°F). The completion of solution or reaction is indicated by liquifaction or clarification of the gel first formed.
3. Allow to cool
4. Run melt point on cooled sample. Melt point should be around 375°F. Addition of lithium stearate increases melt point of original wax considerably.
5. Flake cooled wax.

Mixing instructions for compound BQ

1. Melt paraffin wax, blend in light process oil and then blend in lithium stearate
2. Continue with procedure as described in mixing procedure for stock BP

Mixing procedure for Compound BR

1. Procedure same as compound BP except add GD612 with lithium stearate

Mixing procedure for compound BS

1. Procedure same as for compound BQ except add GD612 with the lithium stearate

Approximate ASTM Melt Point of Wax Preparations

BP - 372°F
BQ - 379°F
BR - 379°F
BS - 363°F

*The formulations and waxes prepared in this experiment were taken from U. S. Patent 2,368,522

Figure 43

Starting Coefficient of Friction - Evaluation of Paraffin Wax Modified with Lithium Stearate in Butadiene-Acrylonitrile Rubber Compound

Polymer - PARACRIL 18-80

Compound - NCw-60-0123-C-3-C

Velocity - 0.30 inches/minute

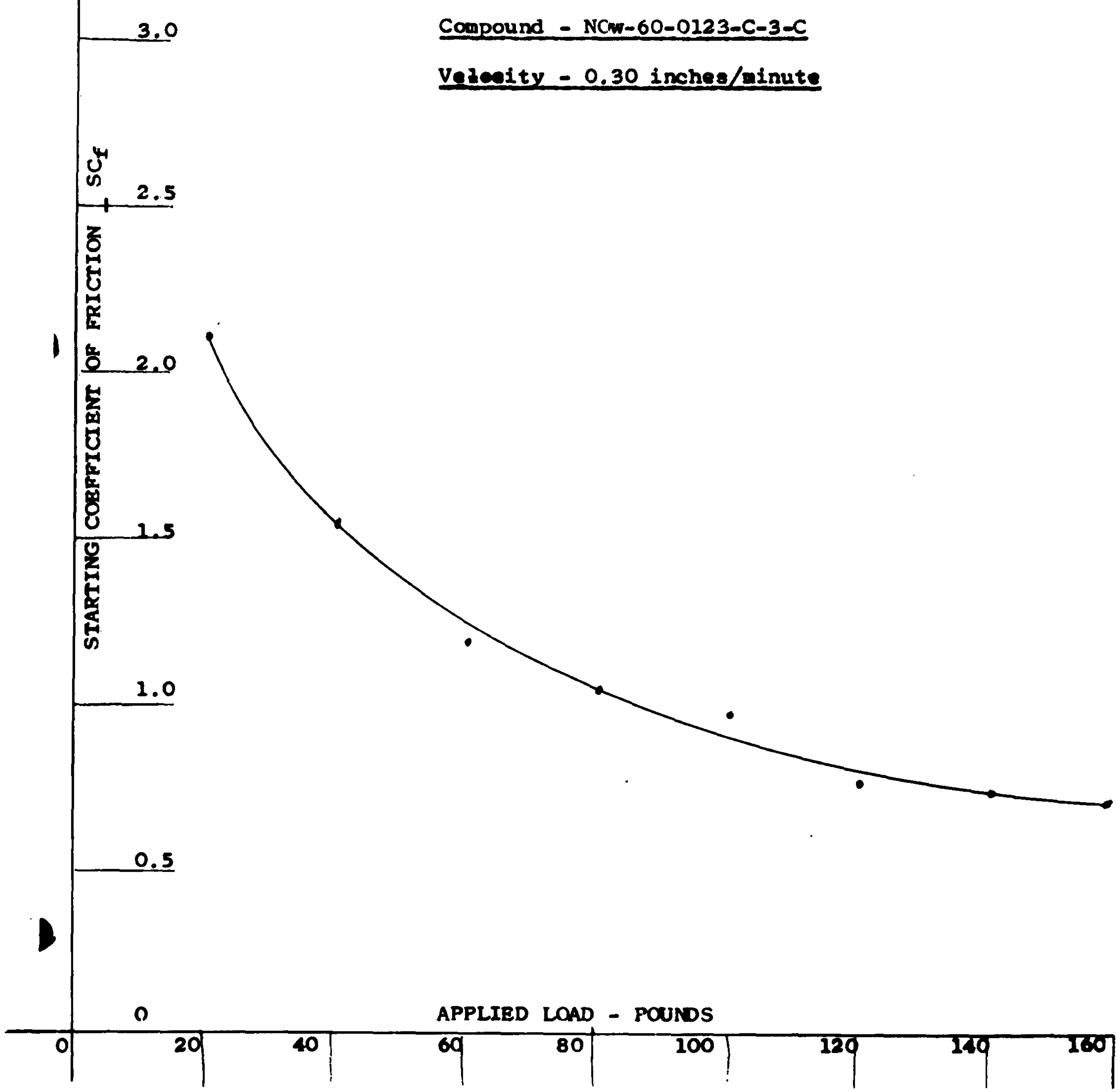


Figure 44

Starting Coefficient of Friction - Evaluation of
Paraffin Wax Modified with Lithium Stearate in a Butadiene-Acrylonitrile
Rubber Compound

Polymer - PARACRIL 18-80, C-29-BP

Compound - NOw-60-0123-C-53-EF

Velocity - 0.30 inches/minute

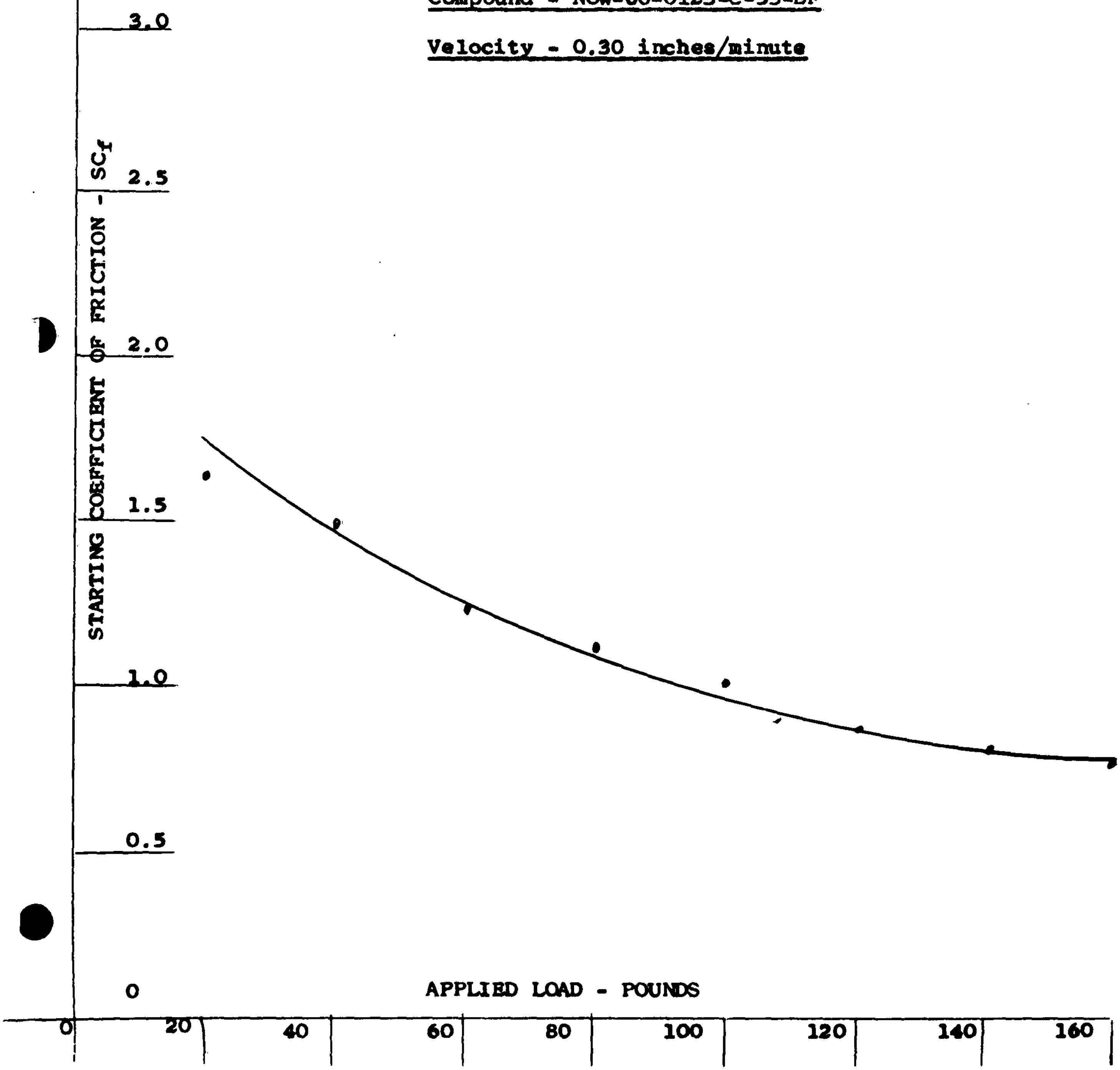


Figure 45

Starting Coefficient of Friction - Evaluation of Paraffin Wax Modified with Lithium Stearate in a Butadiene-Acrylonitrile Rubber Compound

Polymer - PARACRIL 18-80, C-29-BQ

Compound - NOw-60-0123-C-53-BG

Velocity - 0.30 inches/minute

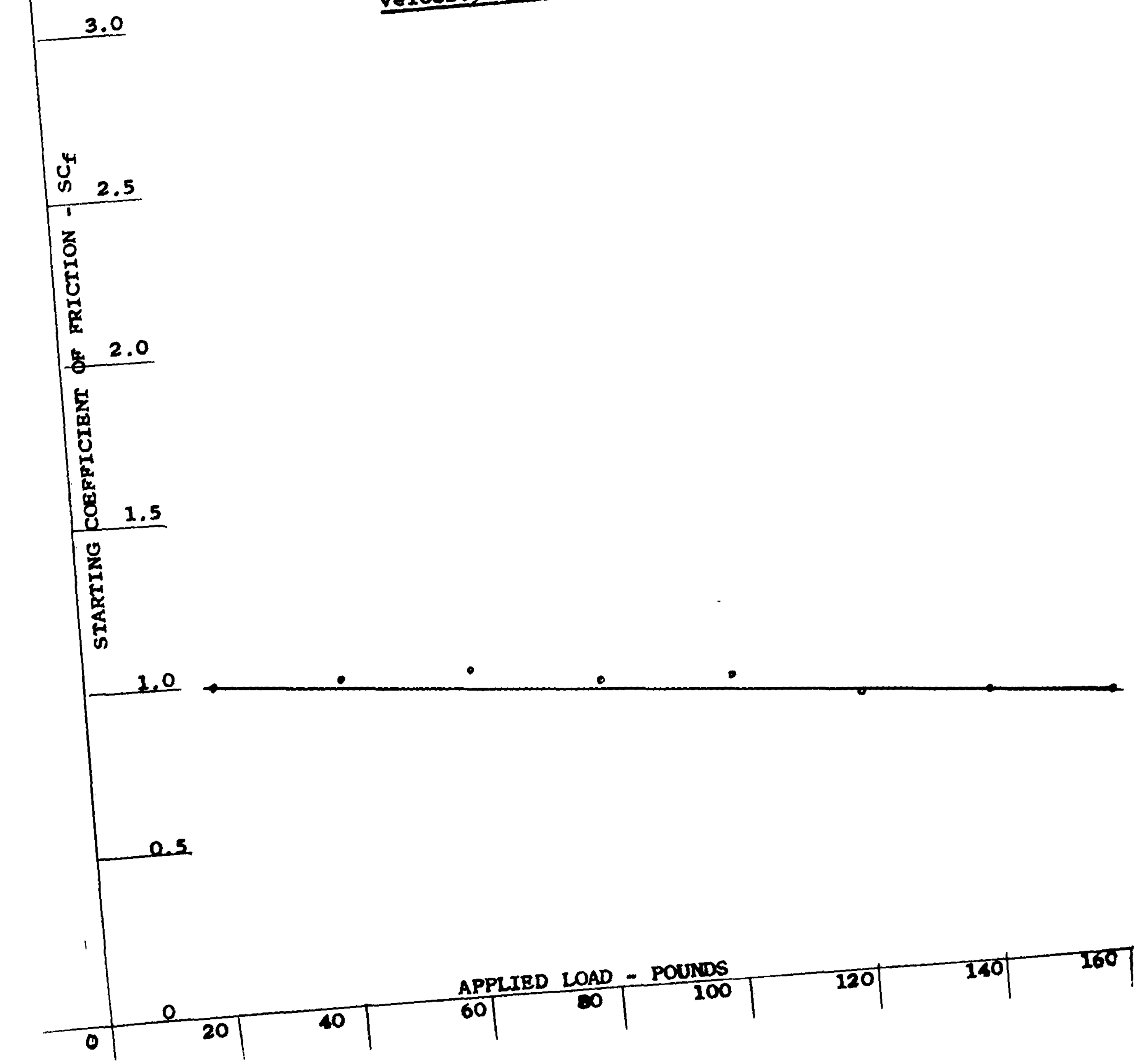


Figure 46

Starting Coefficient of Friction - Evaluation of Paraffin Wax Modified with Lithium Stearate in a Butadiene-Acrylonitrile Rubber Compound

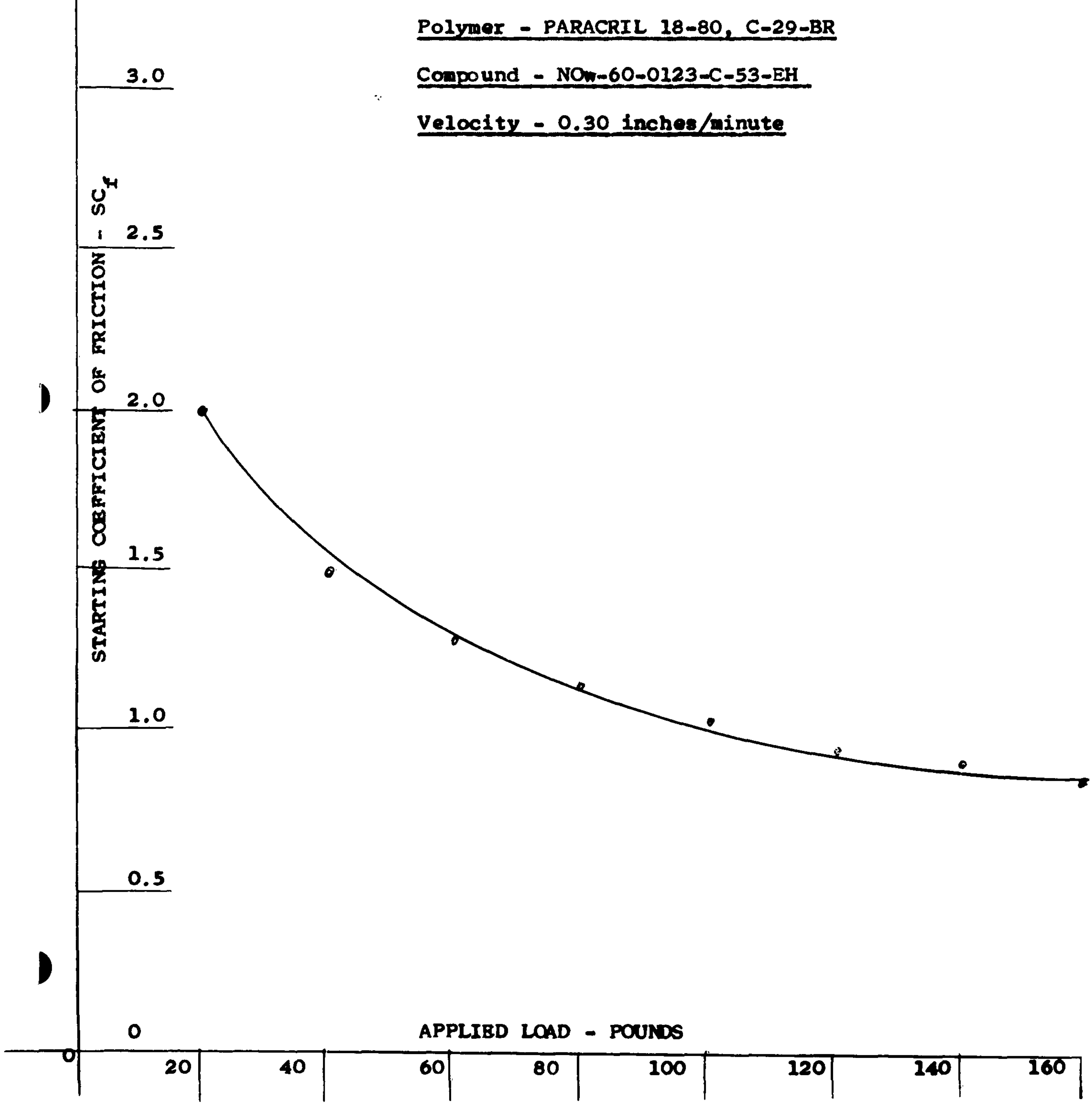


Figure 47

Starting Coefficient of Friction - Evaluation of Paraffin Wax Modified with Lithium Stearate in a Butadiene-Acrylonitrile Rubber Compound

Polymer - PARACRIL 18-80, C-29-BS

Compound - NOw-60-0123-C-53-EI

Velocity - 0.30 inches/minute

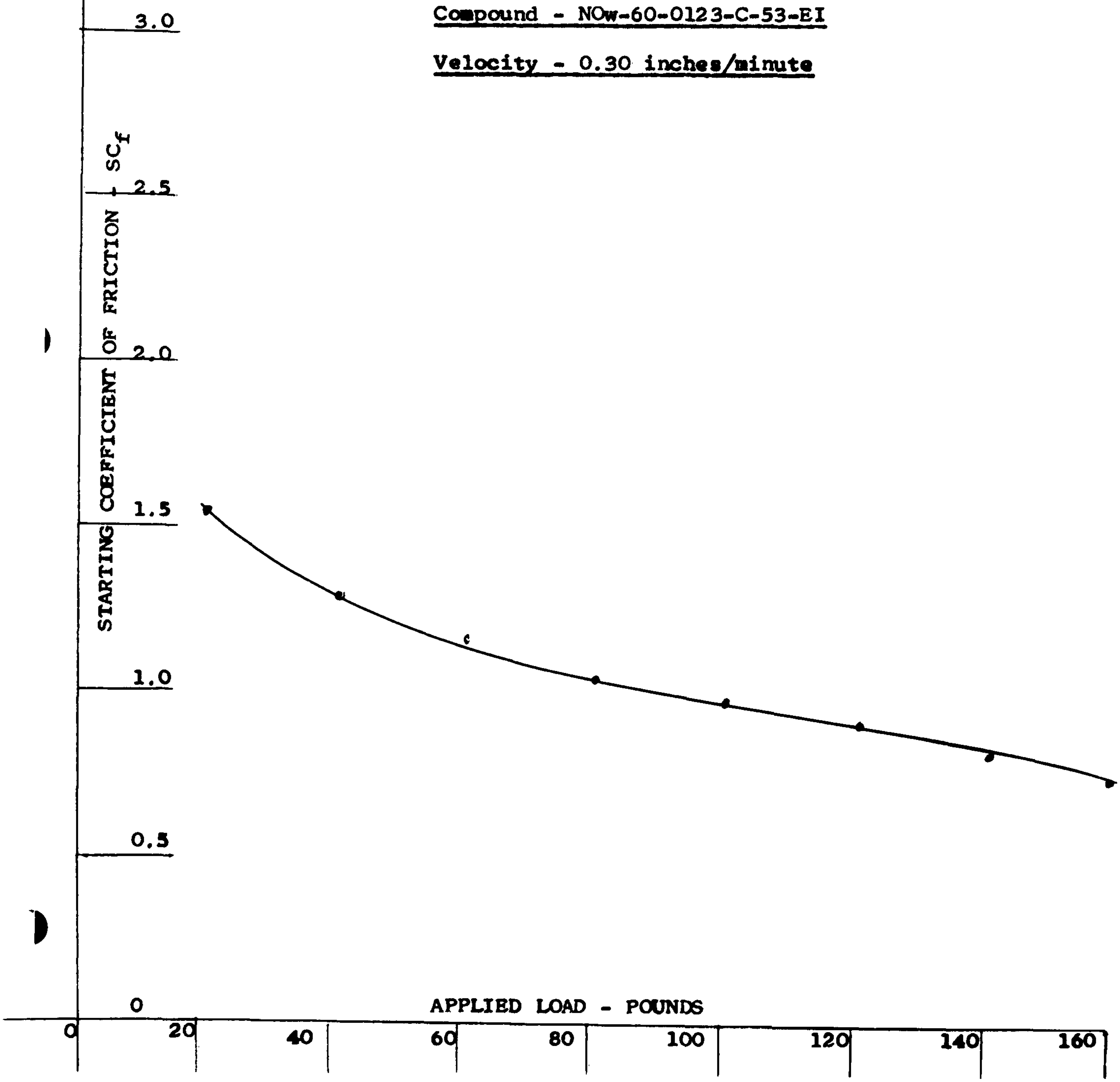


TABLE XIV

Starting Coefficient of Friction

Evaluation of Extreme Pressure Lubricant in

Butadiene-Acrylonitrile Rubber Compound

NOw-60-0123-C	3-C	51-DY
PARACRIL 18-80	100.0	100.0
Zinc Oxide	10.0	10.0
AMINOX	2.0	2.0
Wyex Carbon Black	25.0	25.0
Pelletex Carbon Black	75.0	75.0
Paraplex G-25	10.0	10.0
Plasticizer SC	7.5	7.5
TP-95 Plasticizer	7.5	7.5
TUEX	1.5	1.5
Tetrone A	1.5	1.5
Flexamet PCM 1278	-	2.0
	240.0	242.0

Cure - 30 minutes at 310°F

Test Velocity - 0.30 inches/minute

Applied Load - Pounds	FF	SC_f	FF	SC_f
20	42	2.10	30	1.50
40	62	1.55	55	1.38
60	72	1.20	67	1.12
80	85	1.06	80	1.06
100	98	0.98	100	1.02
120	95	0.79	120	0.91
140	107	0.76	140	0.84
160	113	0.71	160	0.79

Original Physical Properties - Cure 30 minutes at 310°F

	3-C	51-DY
Modulus at 100%, psi	700	800
Tensile, psi	1860	1900
Elongation, %	200	190
Shore "A" Hardness	69	70

Figure 48

Starting Coefficient of Friction - Evaluation of

Extreme Pressure Lubricant in Butadiene-Acrylonitrile Rubber Compound

Polymer - PARACRIL 18-80

Compound - NOw-60-0123-C-3-C

Velocity - 0.30 inches/minute

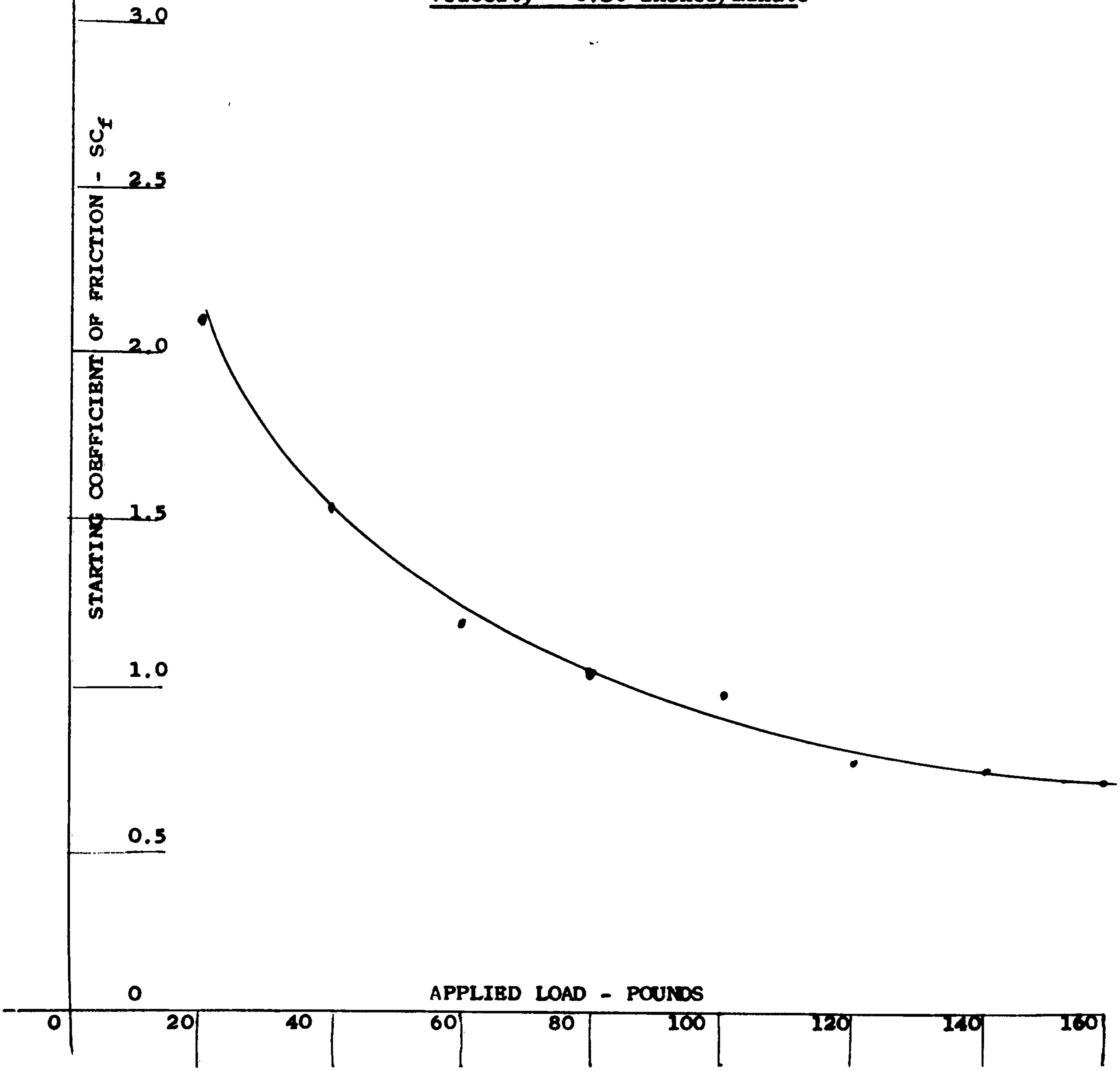


Figure 49

Starting Coefficient of Friction - Evaluation of

Extreme Lubrication in a Butadiene-Acrylonitrile Rubber Compound

Polymer - PARACRIL 18-80

Compound - NOw-60-0123-C-51-DY

Velocity - 0.30 inches/minute

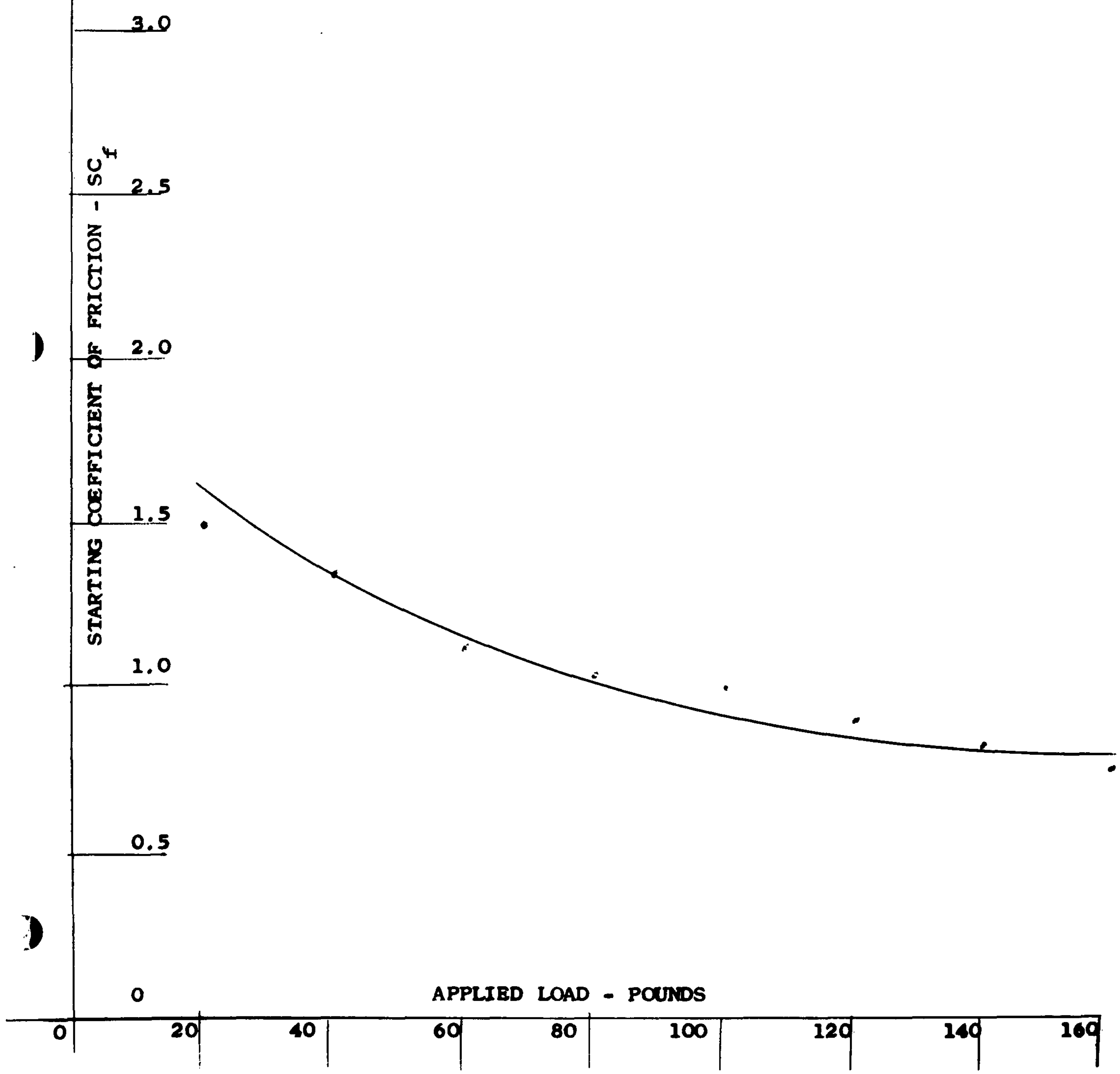


TABLE XV

Starting Coefficient of Friction

Evaluation of Graphite in Fluorocarbon Rubber

NOw-60-0123-C	5-N	40-CX	40-CZ
Viton A	100.0	100.0	100.0
Magnesium Oxide	20.0	20.0	20.0
Thermax MT Carbon Black	20.0	20.0	20.0
Diak #1	1.5	1.5	1.5
Graphite	-	5.0	20.0
	141.5	146.5	161.5

Cure - Press Cure - 30 minutes at 300°F
Oven Post Cure - See Below

Test Velocity - 0.30 inches/minute

Applied Load - Pounds	FF	SC_f	FF	SC_f	FF	SC_f
20	23	1.15	26	1.30	8	0.40
40	26	0.65	38	0.95	23	0.58
60	18	0.30	32	0.53	40	0.67
80	32	0.40	31	0.39	50	0.63
100	30	0.30	59	0.59	59	0.59
120	47	0.38	80	0.67	67	0.56
140	58	0.42	75	0.54	72	0.51
160	62	0.39	64	0.40	79	0.49

Original Physical Properties - Cured as noted

	5-N	40-CX	40-CZ
Modulus at 100%, psi	1100	1250	1890
Tensile, psi	2660	2590	2260
Elongation, %	200	190	120
Shore "A" Hardness	70	75	86

Oven Post Cure - 1 hour at 200°F
1 hour at 250°F
1 hour at 300°F
1 hour at 350°F
25 hours at 400°F

Figure 50

Starting Coefficient of Friction - Evaluation of Graphite in Fluorocarbon Rubber

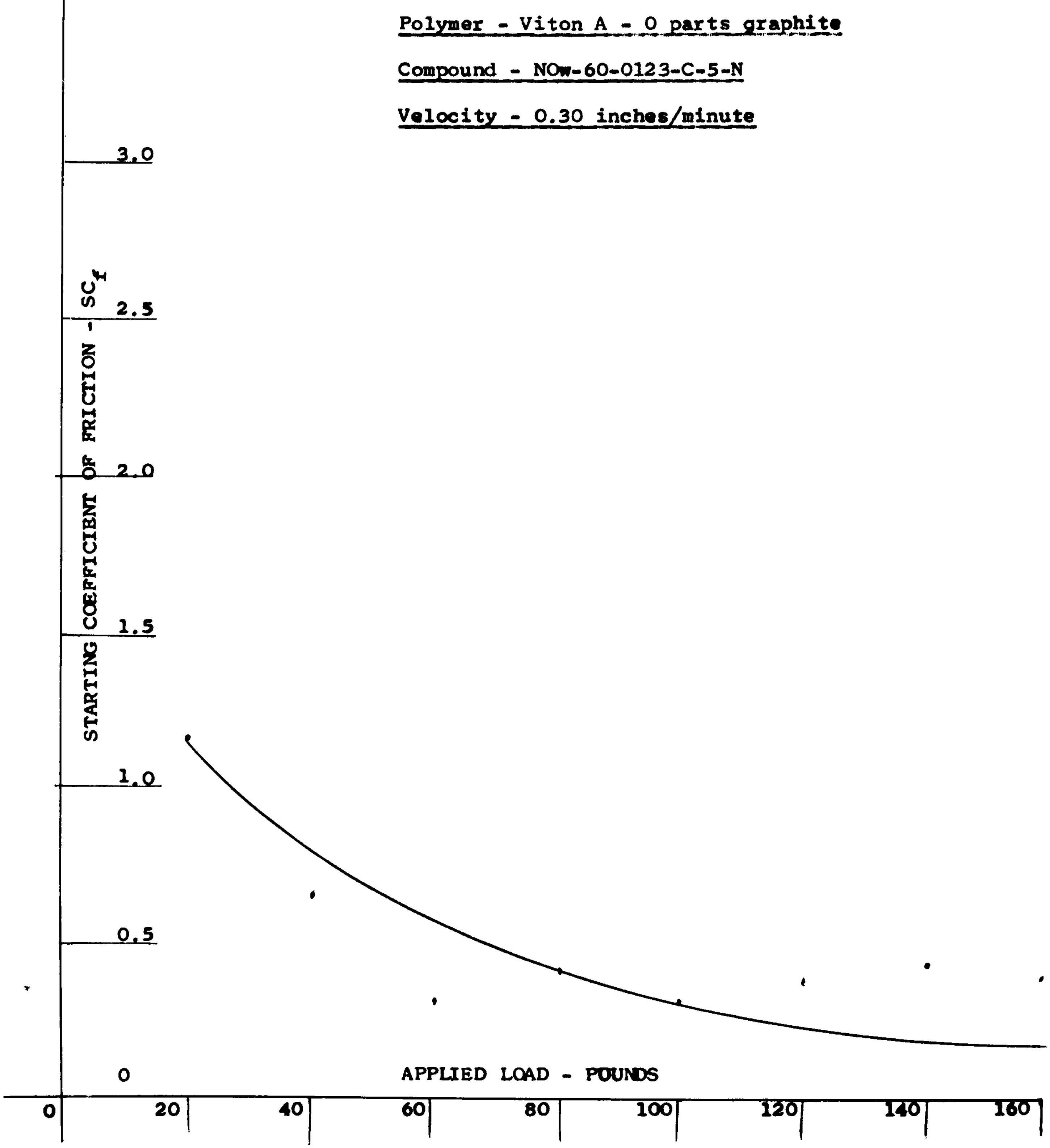


Figure 51

Starting Coefficient of Friction - Evaluation of

Graphite in Fluorocarbon Rubber

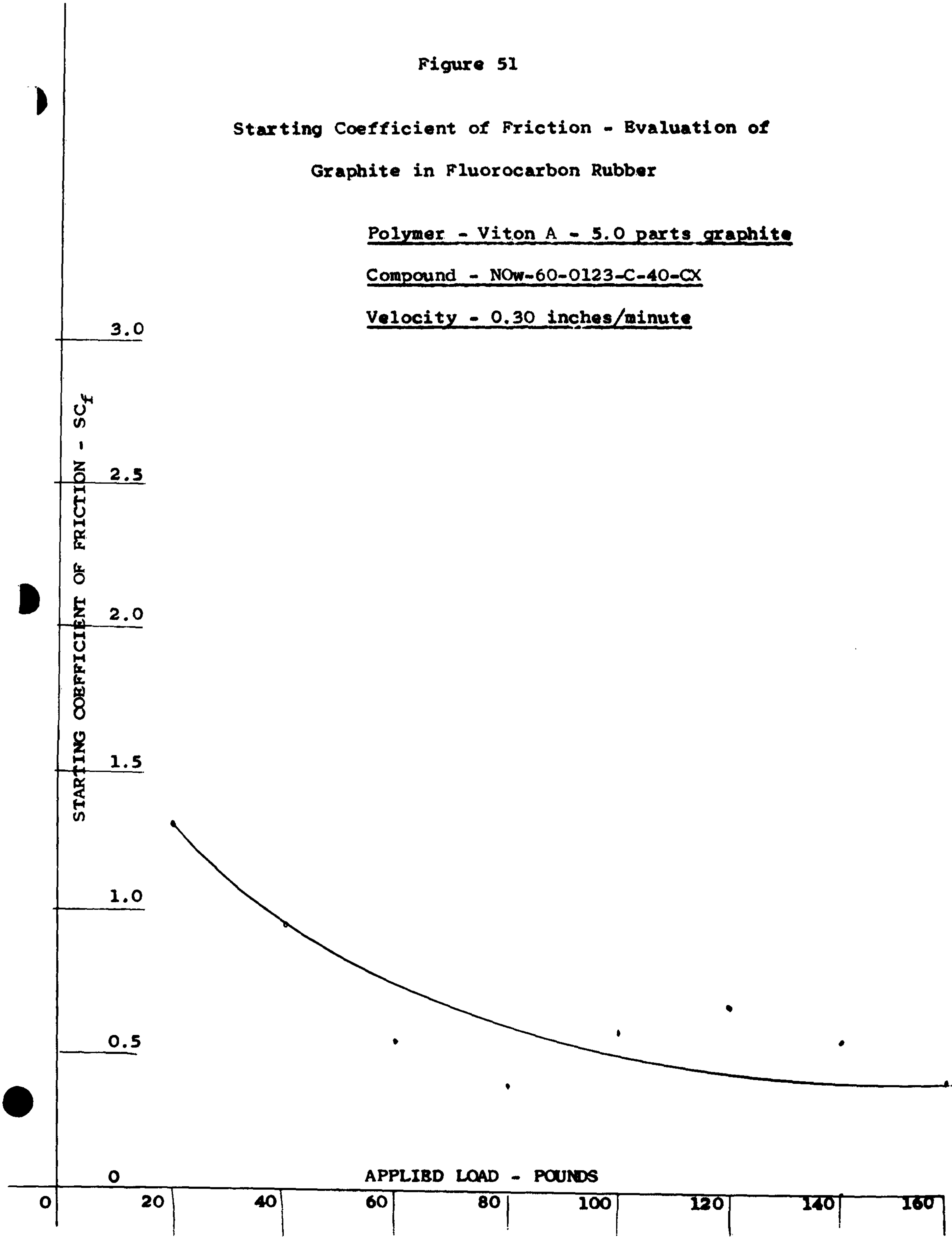


Figure 52

Starting Coefficient of Friction - Evaluation of

Graphite in Fluorocarbon Rubber

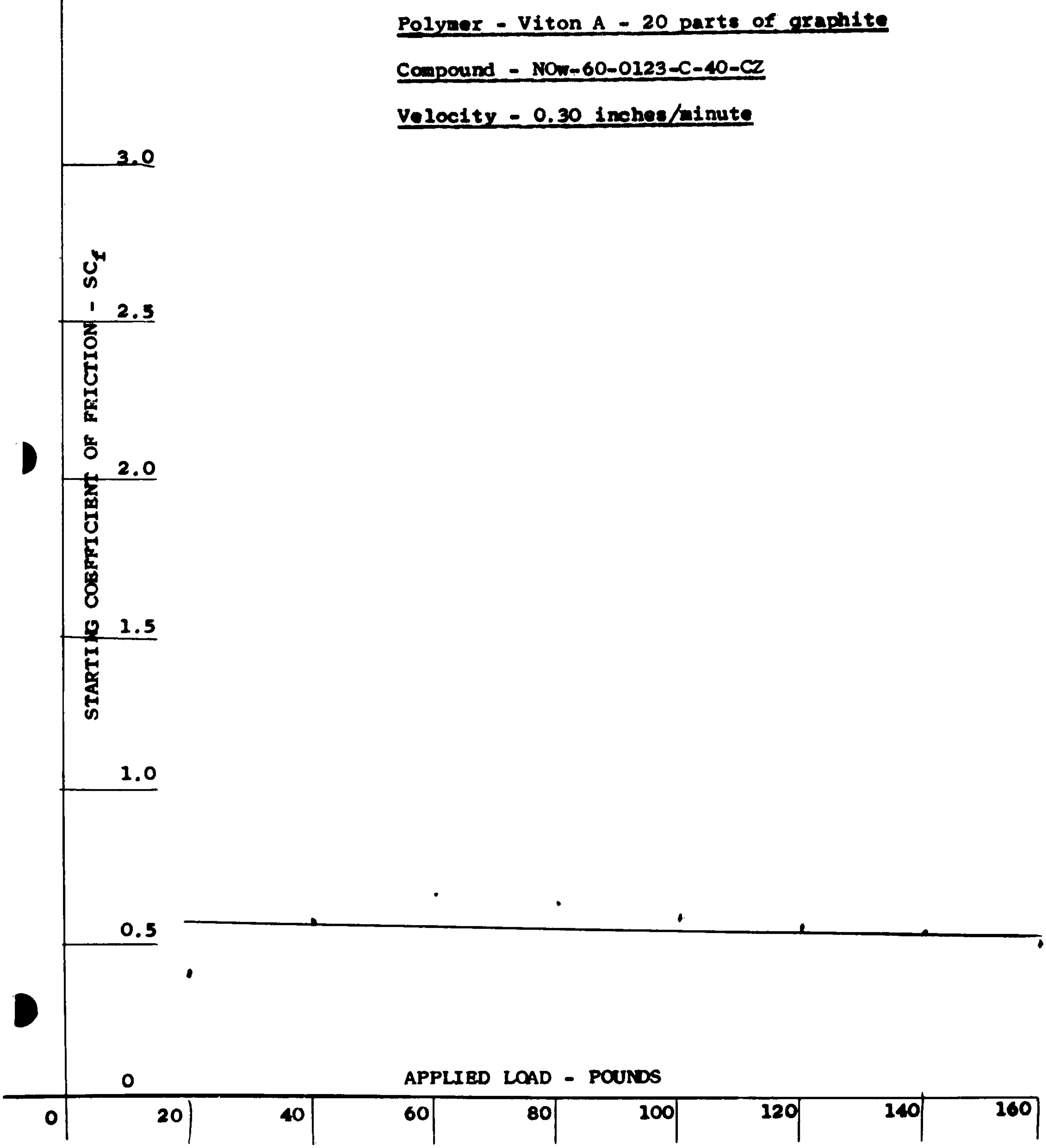


TABLE XVI

Starting Coefficient of Friction

Evaluation of Fluorocarbon Resin in Fluorocarbon Rubber Compounds

NOw-60-0123-C	6-P	45-DN	45-DO
Kel F Elastomer 3700	100.0	100.0	100.0
Kel F Resin 800	-	25.0	50.0
Zinc Oxide	10.0	10.0	10.0
Dyphos	10.0	10.0	10.0
Thermax MT Carbon Black	15.0	15.0	15.0
Diak No. 1	3.0	3.0	3.0
	138.0	163.0	188.0

Cure - 30 minutes at 300°F
Air Oven Post Cure - 16 hrs at 300°F

Test Velocity - 0.30 inches/minute

Applied Load - Pounds	FF	SC_f	FF	SC_f	FF	SC_f
20	25	1.25	26	1.30	18	0.90
40	48	1.20	43	1.08	37	0.93
60	50	0.83	48	0.80	47	0.78
80	54	0.68	68	0.85	48	0.60
100	77	0.77	72	0.72	76	0.76
120	80	0.67	82	0.68	88	0.73
140	90	0.64	105	0.75	118	0.84
160	70	0.44	117	0.73	118	0.74

Original Physical Properties - Cure as indicated above

Modulus at 100%, psi	490	980	1650
Tensile, psi	1800	3070	2540
Elongation, %	180	180	300
Shore "A" Hardness	66	85	92

Figure 53

Starting Coefficient of Friction - Evaluation of

Fluorocarbon Resin in Fluorocarbon Rubber Compounds

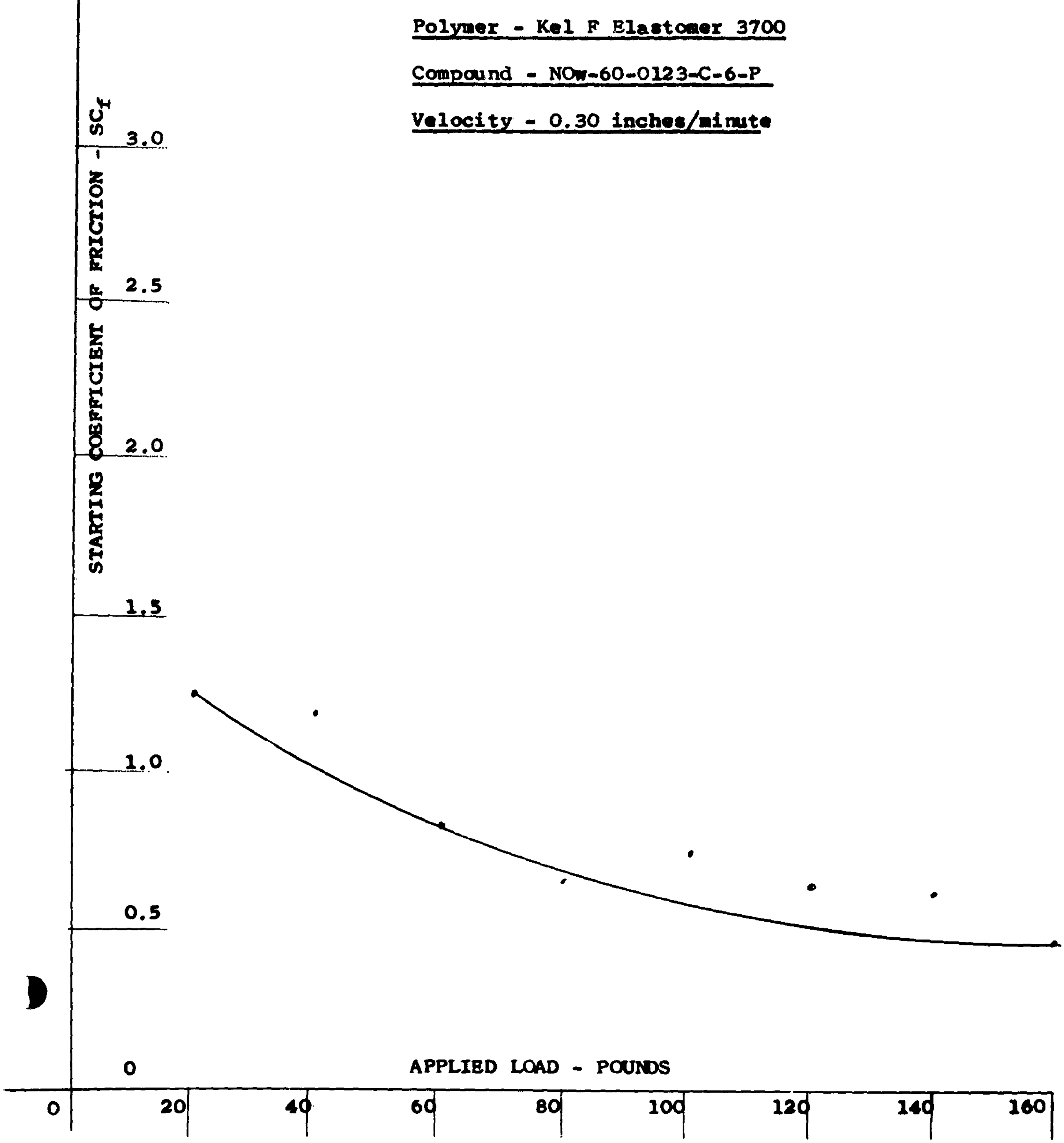


Figure 54

Starting Coefficient of Friction - Evaluation of

Fluorocarbon Resin in Fluorocarbon Rubber Compounds

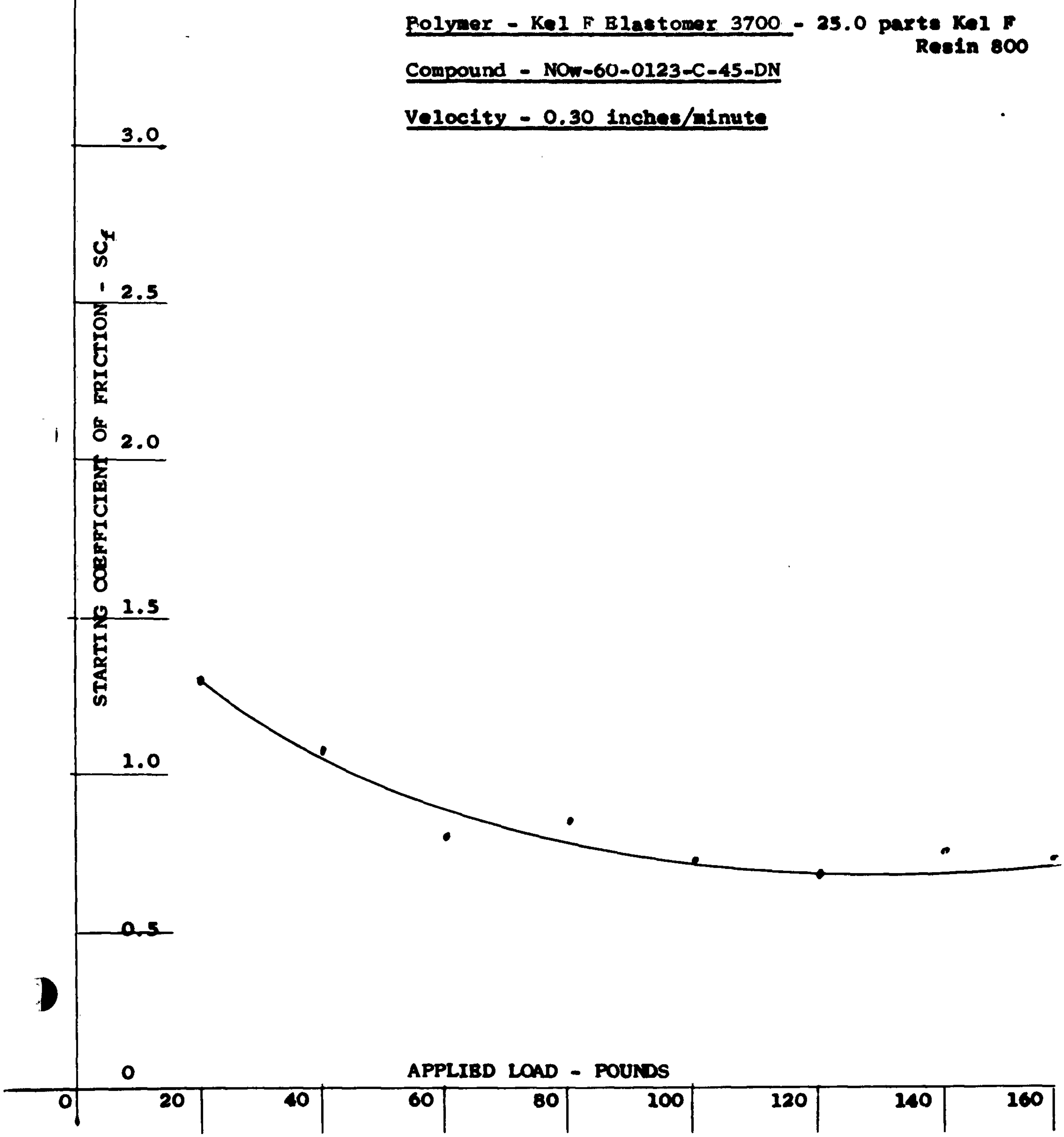


Figure 55

Starting Coefficient of Friction - Evaluation of

Fluorocarbon Resin in Fluorocarbon Rubber Compounds

Polymer - Kel F Elastomer 3700 - 50.0 parts Kel F Resin 800

Compound - NOw-60-0123-C-45-DO

Velocity - 0.30 inches/minute

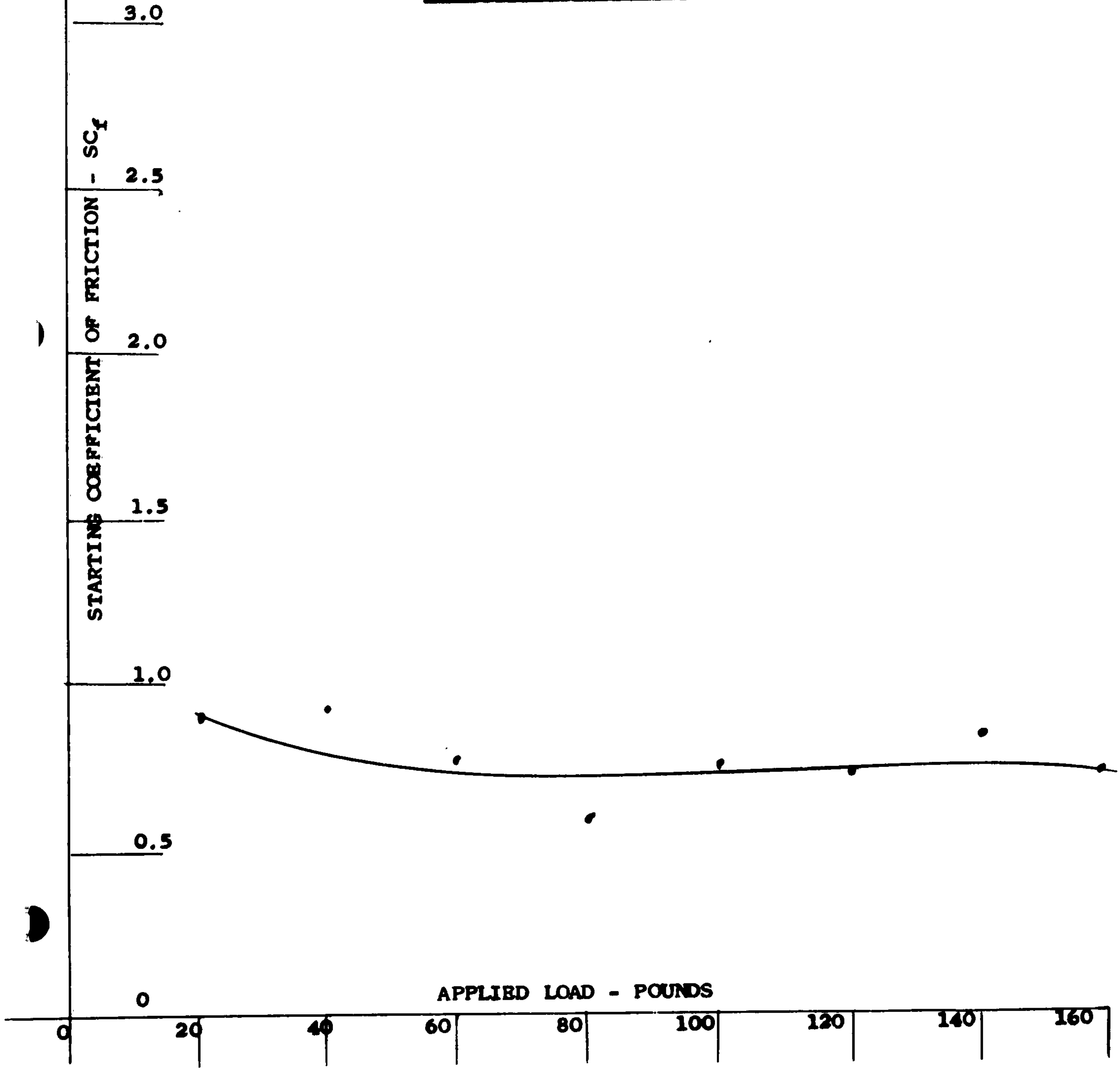


TABLE XVII

Starting Coefficient of Friction

Evaluation of Lithium Stearate Modified Wax in a Fluorocarbon Rubber Compound

NOw-60-0123-C	58-BW	58-EX	59-EY	59-EZ
Viton A	100.0	100.0	-	-
Kel F Elastomer 3700	-	-	100.0	100.0
Magnesium Oxide	20.0	20.0	-	-
Zinc Oxide	-	-	10.0	10.0
Thermax MT Carbon Black	20.0	20.0	15.0	15.0
Dyphos	-	-	10.0	10.0
Diak #1	1.5	1.5	3.0	3.0
C-29-BQ	-	2.0	-	2.0
	141.5	143.5	138.0	140.0

Test Specimen Cure -Press Cure - 30 minutes at 300°F
Air Oven Cure - 1 hour at 200°F
1 hour at 250°F
1 hour at 300°F
1 hour at 350°F
24 hours at 400°F

Air Oven Cure 16 hours at 300°F

Test Velocity - 0.30 inches/minute

Applied Load - Pounds	FF	SC_f	FF	SC_f	FF	SC_f	FF	SC_f
20	29	1.45	22	1.10	25	1.25	19	0.95
40	47	1.18	54	1.35	27	0.68	34	0.85
60	74	1.23	74	1.23	59	0.98	65	1.08
80	114	1.43	101	1.26	72	0.90	60	0.75
100	81	0.81	124	1.24	62	0.63	45	0.45
120	74	0.62	128	1.07	83	0.69	31	0.26
140	104	0.74	127	0.91	131	0.94	81	0.58
160	162	1.01	153	0.96	134	0.84	93	0.58

Original Physical Properties - Press Cured 30 minutes at 300°F followed by Post Cure at Noted Above

Modulus at 100%,psi	730	670	1030	580
Tensile, psi	2240	1950	1640	1270
Elongation, %	250	240	130	140
Shore "A" Hardness	75	75	; 76	74

Figure 56

Starting Coefficient of Friction - Evaluation of Lithium Stearate Modified Wax in a Fluorocarbon Rubber Compound

Polymer - Viton A

Compound - NOw-60-0123-C-58-EW

Velocity - 0.30 inches/minute

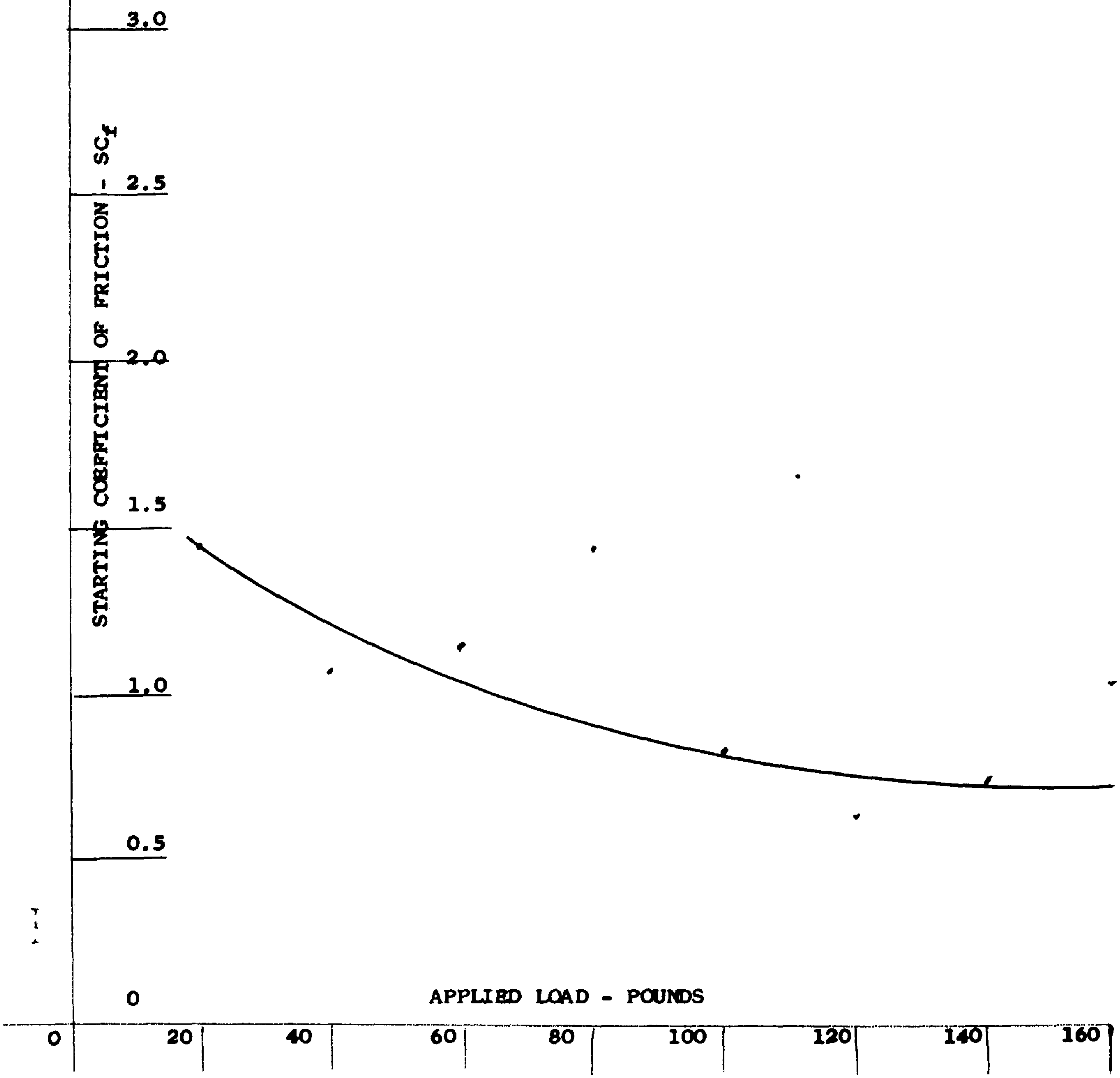


Figure 57

Starting Coefficient of Friction - Evaluation of

Lithium Stearate Modified Wax in a Fluorocarbon Rubber Compound

Polymer - Viton A, C-29-BQ

Compound - NOw-60-0123-C-58-EX

Velocity - 0.30 inches/minute

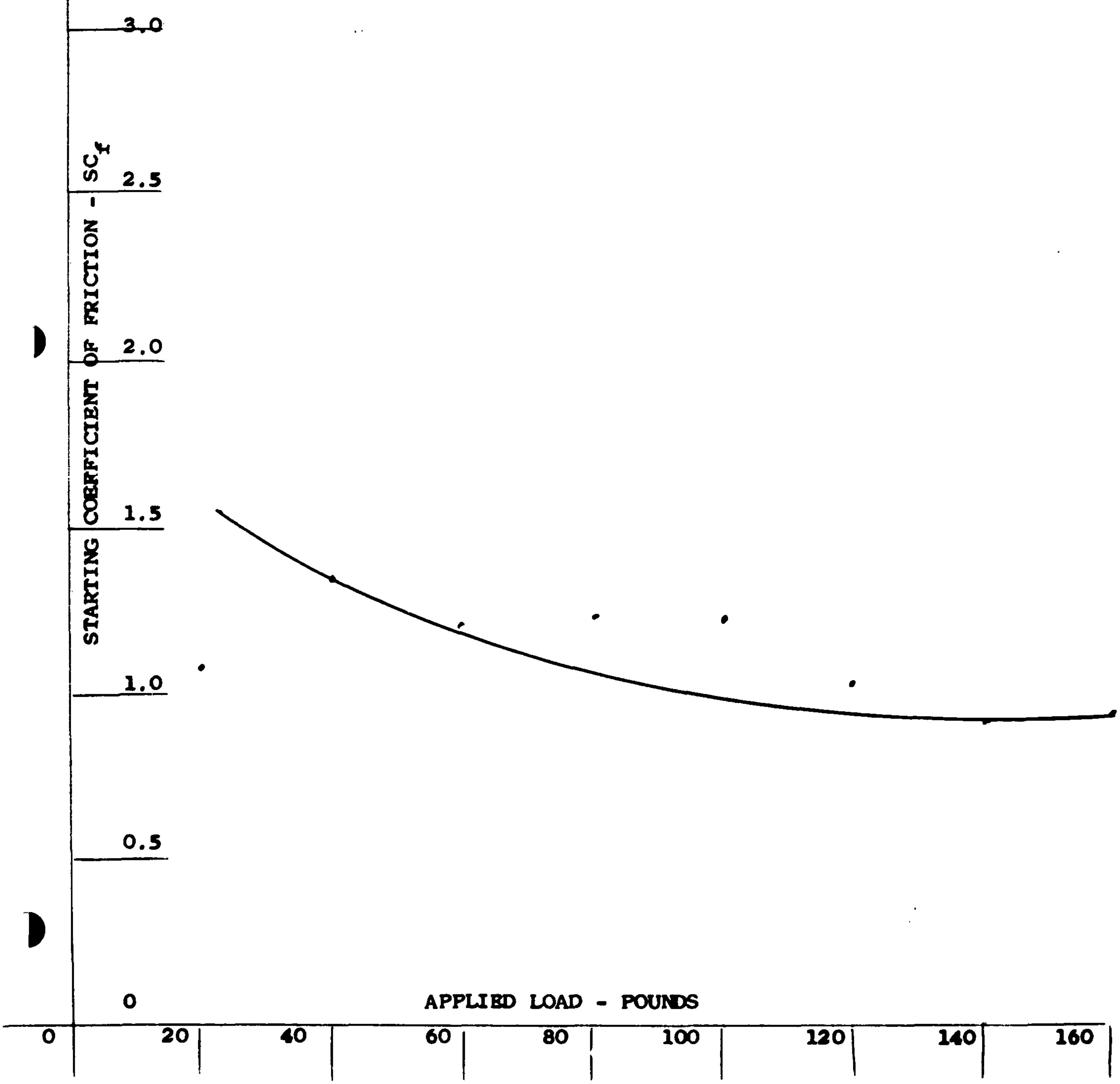


Figure 58

Starting Coefficient of Friction - Evaluation of

Lithium Stearate Modified Wax in a Fluorocarbon Rubber Compound

Polymer - Kel F Elastomer 3700

Compound - NOw-60-0123-C-59-BY

Velocity - 0.30 inches/minute

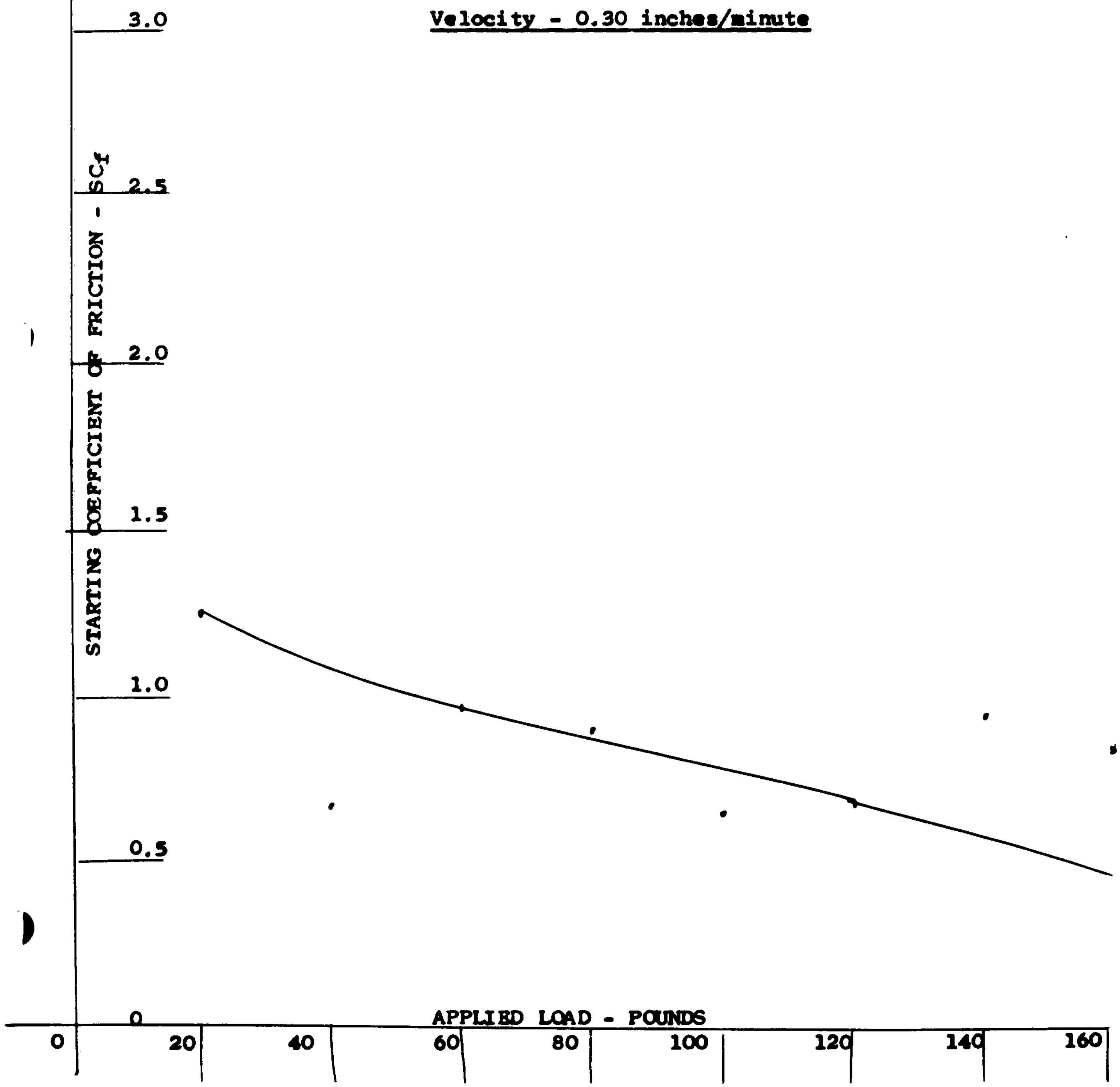


Figure 59

Starting Coefficient of Friction - Evaluation of

Lithium Stearate Modified Wax in a Fluorocarbon Rubber Compound

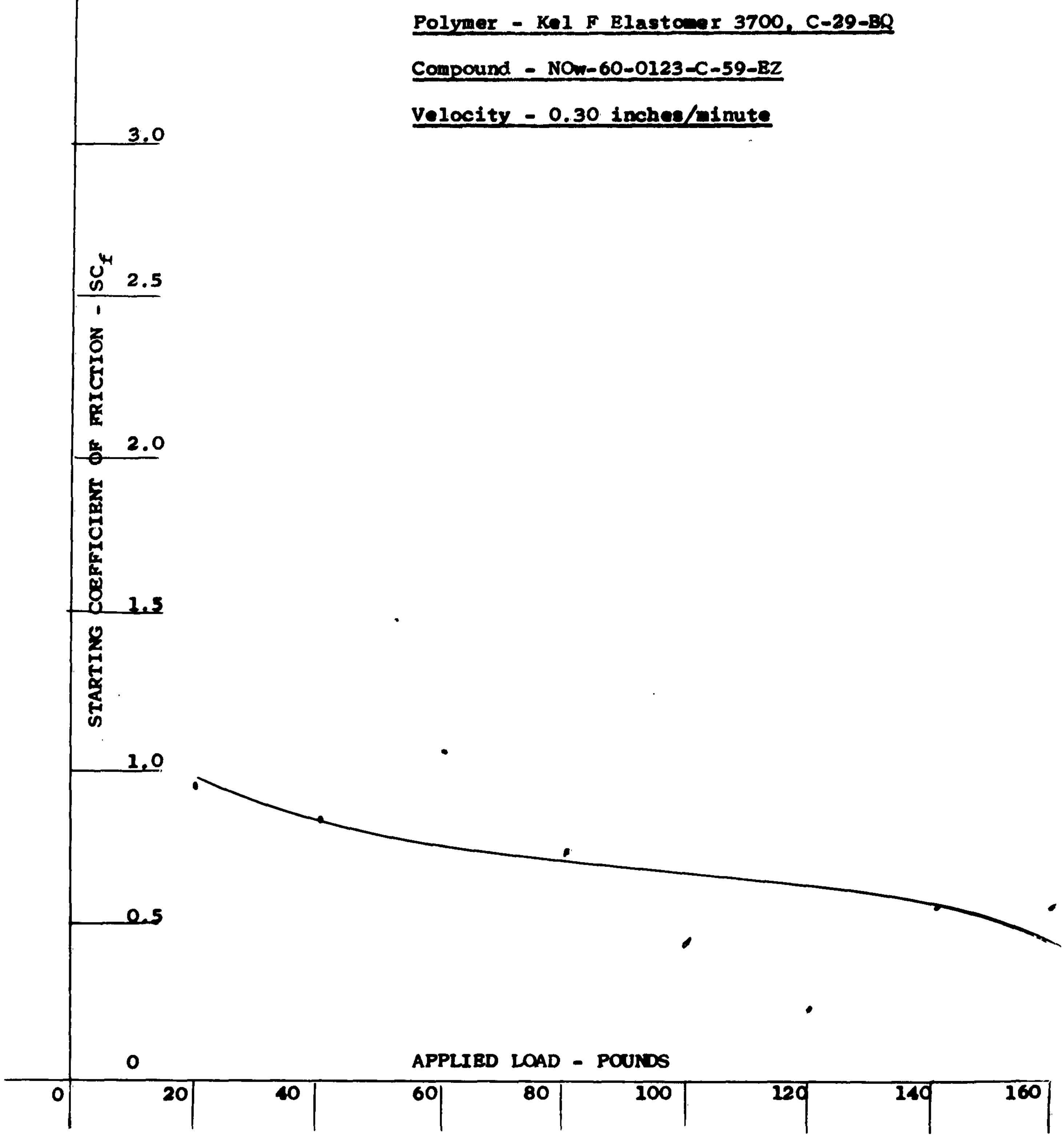


TABLE XVIII

Starting Coefficient of Friction

Evaluation of Fluorocarbon Telomers and Dispersions in a Polysulfide Rubber Compound

NOw-60-0123-C	55-EM	55-EN	55-EO
Thiokol ST	100.0	100.0	100.0
Stearic Acid	0.5	0.5	0.5
G-M-F	1.5	1.5	1.5
Zinc Oxide	0.5	0.5	0.5
Philblack A Carbon Black	20.0	20.0	20.0
Statex B Carbon Black	30.0	30.0	30.0
Vydax A	-	1.0	-
TLT-111	-	-	1.0
	152.5	153.5	153.5

Cure 30 minutes at 287°F

Test Velocity - 0.30 inches/minute

Applied Load - Pounds	FF	SC_f	FF	SC_f	FF	SC_f
20	14	0.70	16	0.80	19	0.95
40	26	0.65	26	0.65	34	0.85
60	37	0.62	46	0.77	59	0.98
80	52	0.65	50	0.63	63	0.79
100	65	0.65	70	0.70	69	0.69
120	84	0.70	80	0.67	68	0.57
140	72	0.51	68	0.49	66	0.47
160	77	0.48	76	0.48	93	0.58

Original Physical Properties - Cure - 30 minutes at 287°F

Modulus at 100%, psi	550	550	540
Tensile, psi	1460	1490	1420
Elongation, %	310	320	300
Shore "A" Hardness	63	67	65

Figure 60

Starting Coefficient of Friction - Evaluation of

Fluorocarbon Telomers and Dispersions in a Polysulfide Rubber Compound

Polymer - Thiokol ST

Compound - NOw-60-0123-C-55-EM

Velocity - 0.30 inches/minute

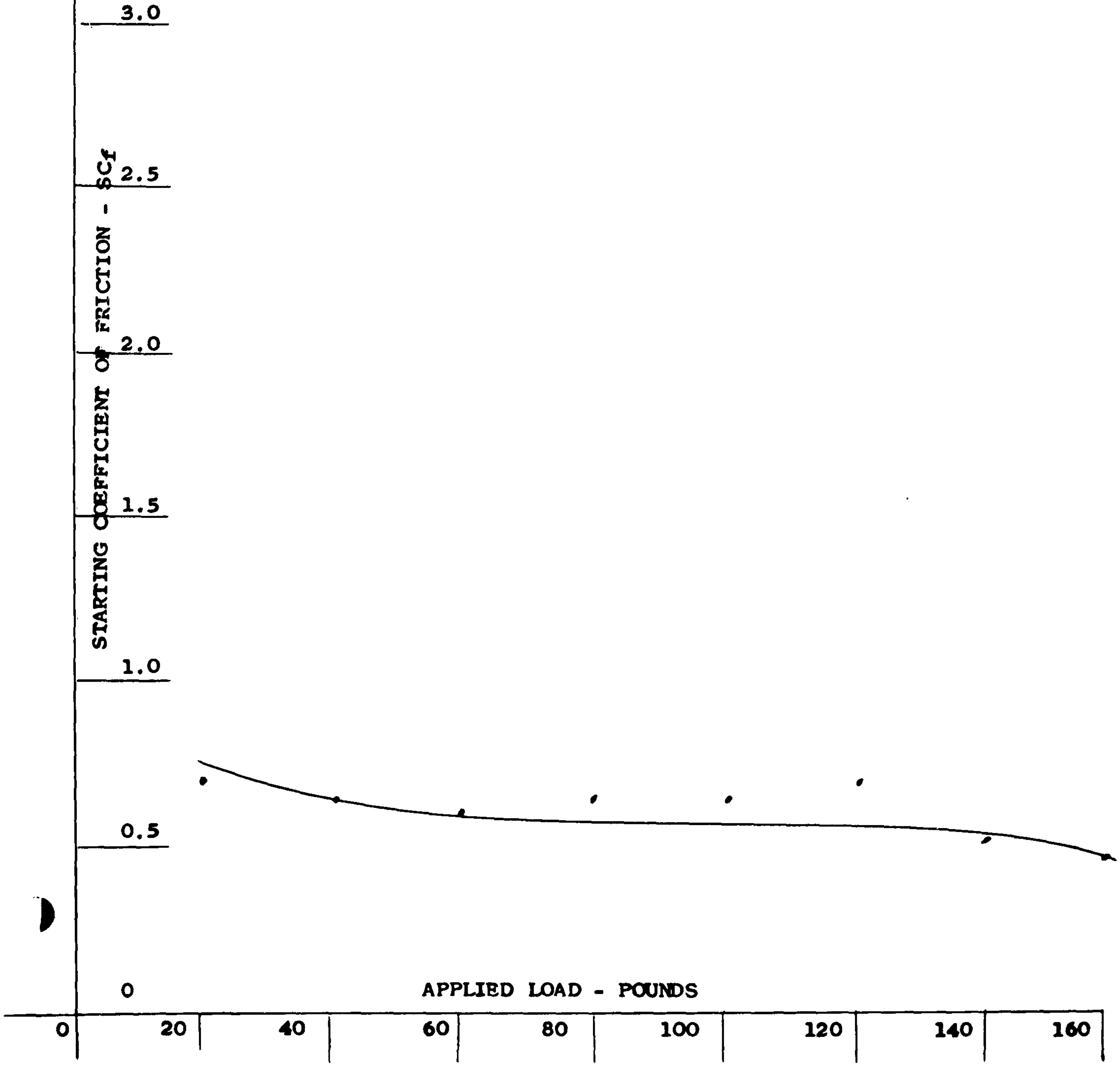


Figure 61

Starting Coefficient of Friction - Evaluation of

Fluorocarbon Telomers and Dispersions in a Polysulfide Rubber Compound

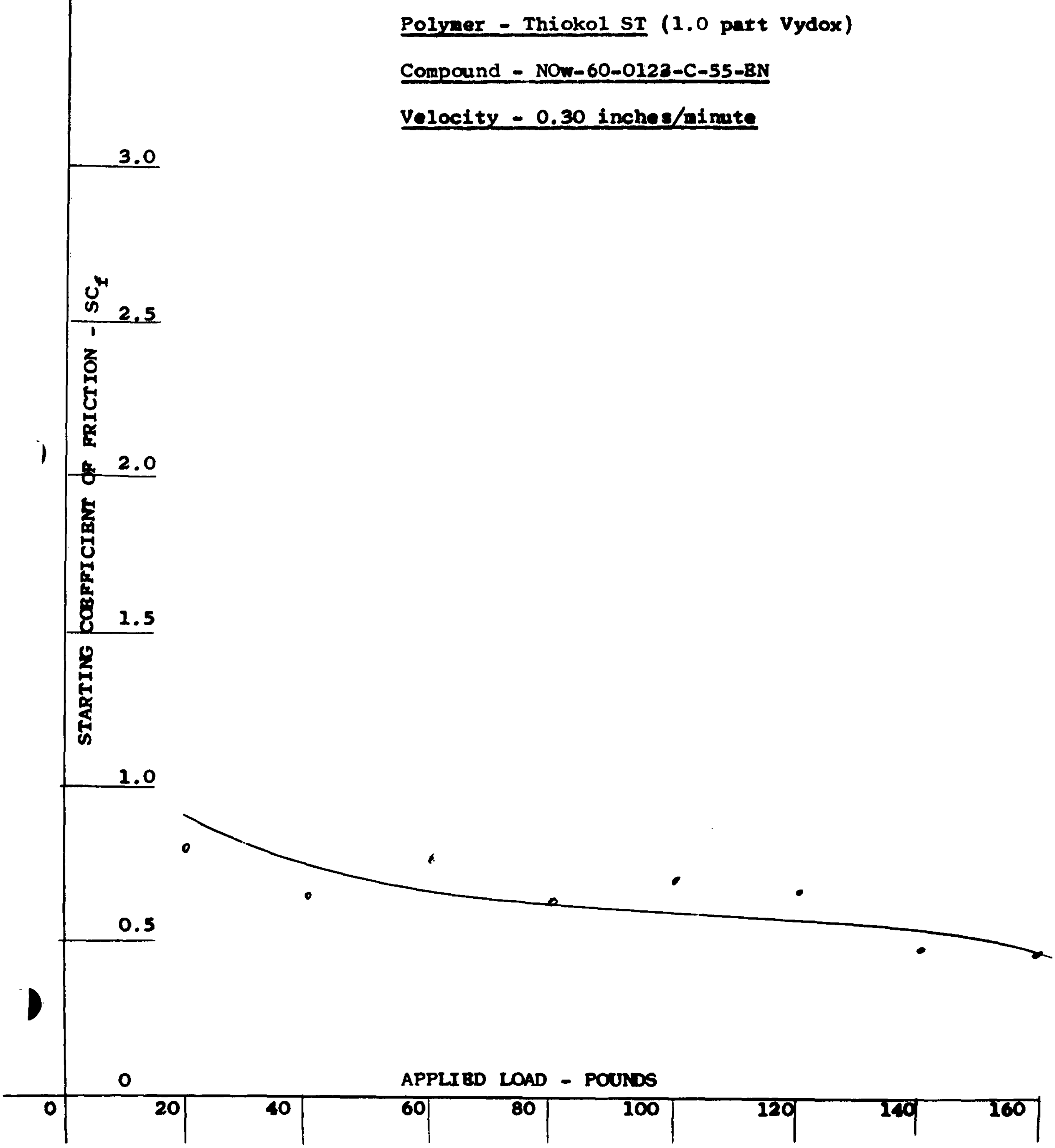


Figure 62

Starting Coefficient of Friction - Evaluation of

Fluorocarbon Telomers and Dispersions in a Polysulfide Rubber Compound

Polymer - Thiokol ST (1.0 part TLT-111)

Compound - NOw-60-0123-C-55-EO

Velocity - 0.30 inches/minute

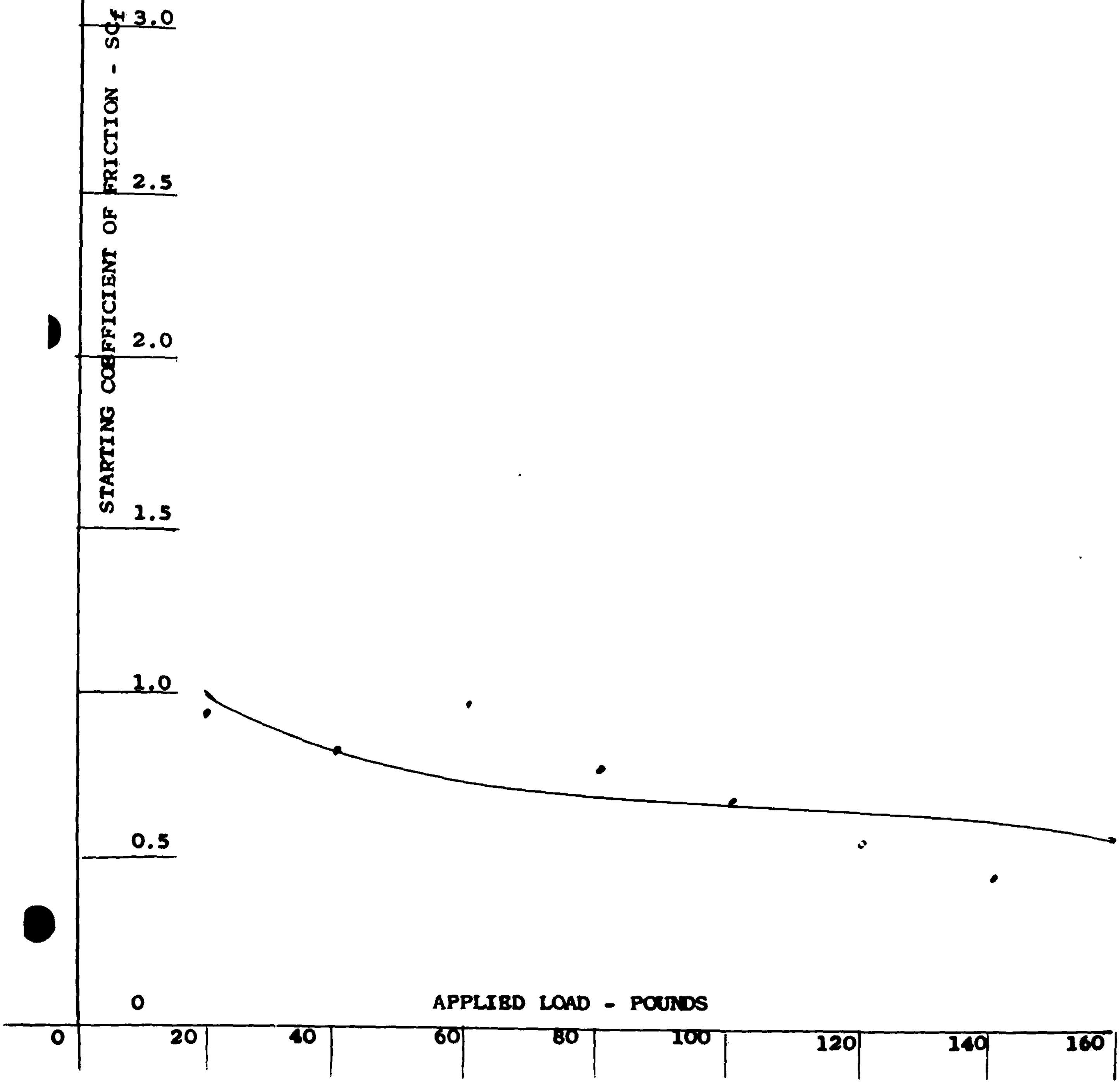


TABLE XIX

Starting Coefficient of Friction

Evaluation of Silicone Rubbers

NOw-60-0123-C	38-CR		38-CS	
	Silastic LS-53		Silastic 82	
	(Fully Compounded by Supplier)			

Test Specimen Cure - 10 minutes at 240°F - Press
8 hours at 392°F - Air Oven Post Cure

Applied Load - Pounds	FF	SC_f	FF	SC_f
20	26	1.30	22	1.10
40	42	1.05	38	0.95
60	55	0.92	57	0.95
80	66	0.83	67	0.84
100	76	0.76	70	0.70
120	88	0.73	73	0.61
140	98	0.70	79	0.56
160	102	0.64	88	0.55

Original Physical Properties - Cure 10 minutes at 240°F - Press
8 Hrs. at 392°F-Air Oven Post Cure

	38-CR	38-CS
Modulus at 100%,psi	360	400
Tensile, psi	1060	1070
Elongation, %	200	270
Shore "A" Hardness	59	77

Figure 63

Starting Coefficient of Friction - Evaluation of Silicone Rubbers

Polymer - Silastic LS-63

Compound - NOw-60-0123-C-38-CR

Velocity - 0.30 inches/minute

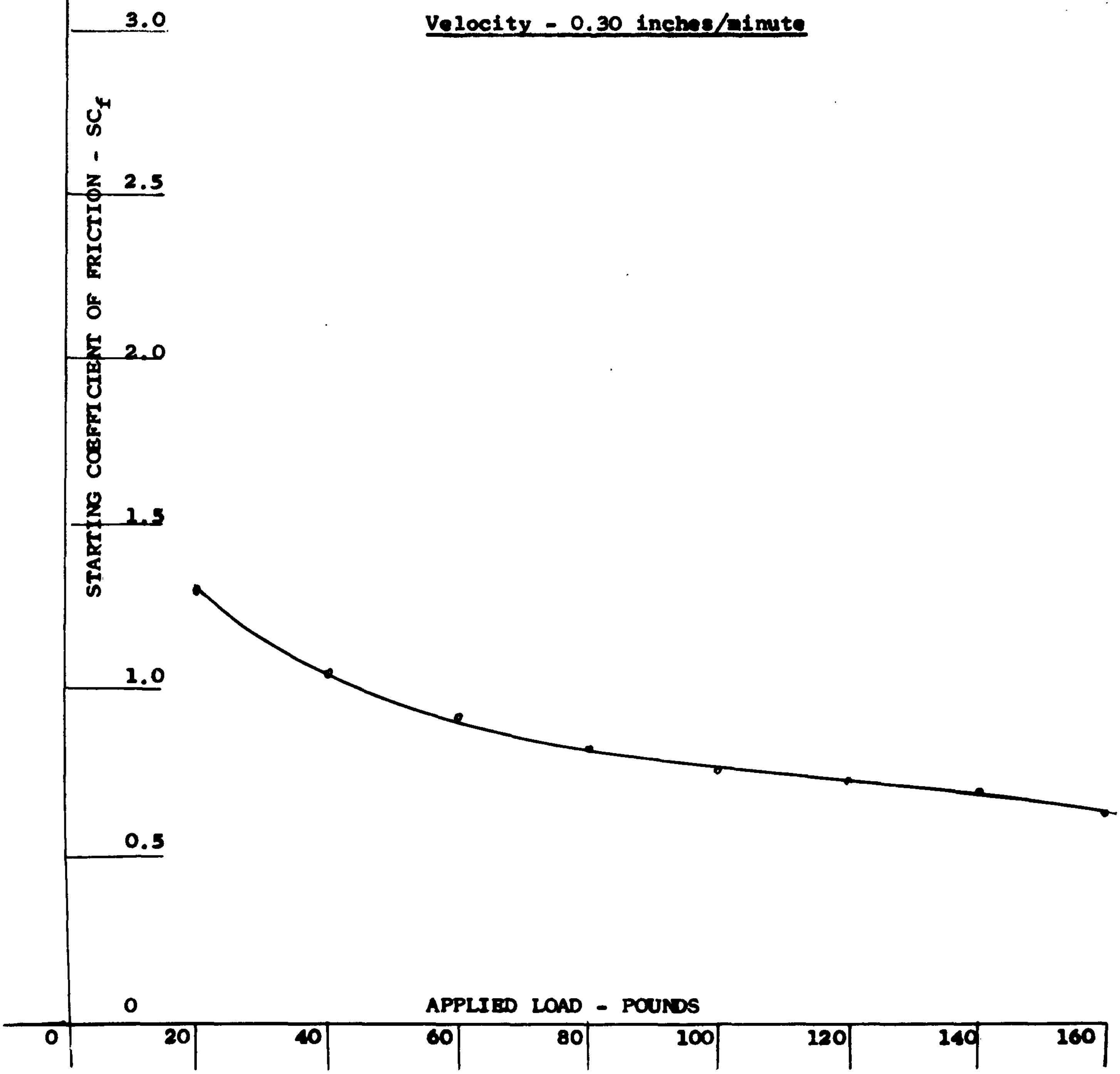


Figure 64

Starting Coefficient of Friction - Evaluation

Silicone Rubbers

Polymer - Silastic 82

Compound - NOw-60-0123-C-38-CS

Velocity - 0.30 inches/minute

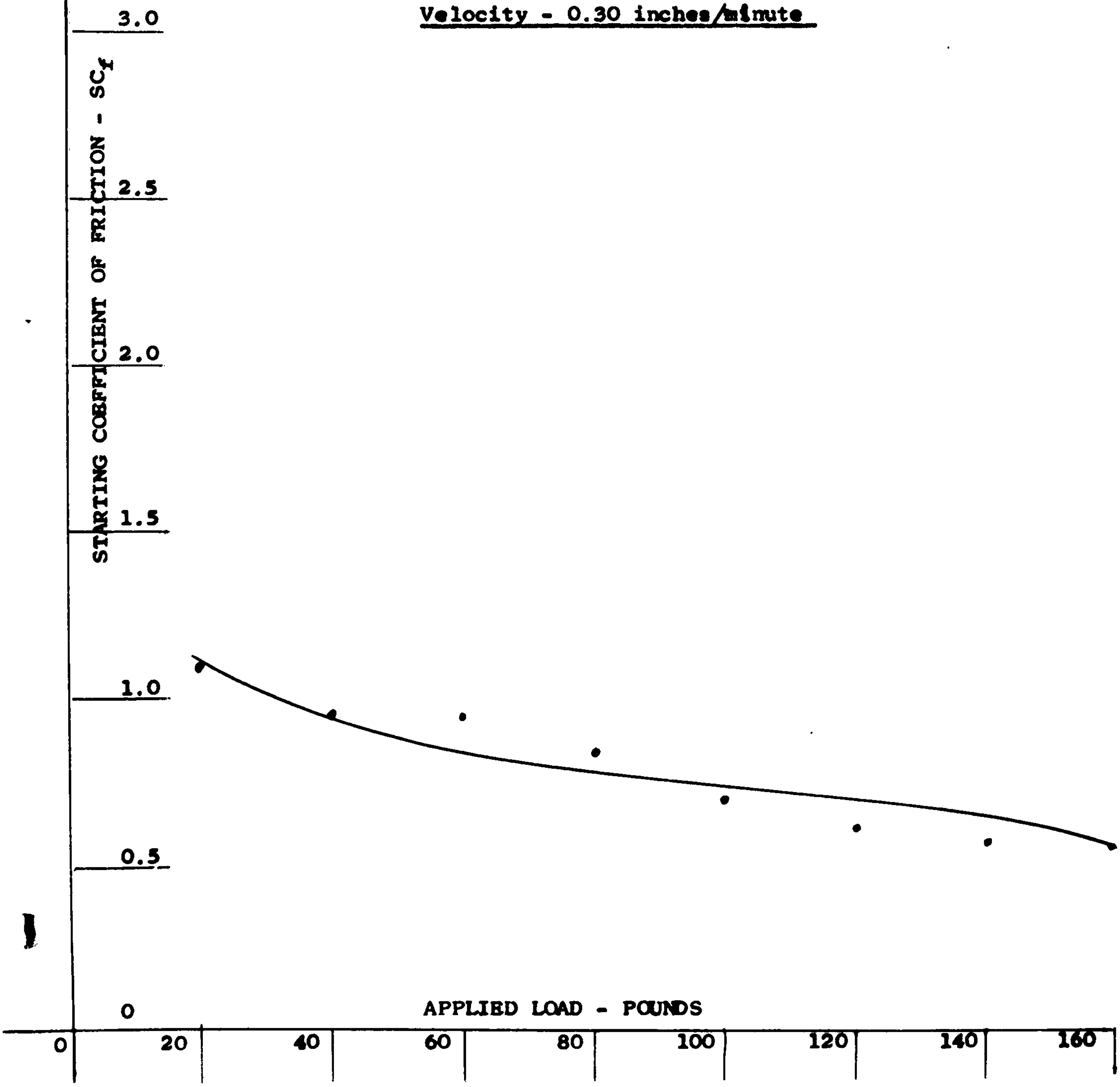


TABLE XX

Starting Coefficient of Friction

Evaluation of Experimental Polybutadiene Rubbers

NOw-60-0123-C	39-CU	39-CV
Phillips Polybutadiene	-	100.0
EMBR (2706B)	100.0	-
FLEXZONE 3-C	1.5	1.5
Philrich #5	5.0	5.0
Resin 731-D	5.0	5.0
Zinc Oxide	3.0	3.0
Philblack O Carbon Black	50.0	50.0
Stearic Acid	1.0	1.0
DELAC-S	0.9	0.9
Sulfur	2.0	2.0
	168.4	168.4

Cure - 15 minutes at 330°F

Test Velocity - 0.30 inches/minute

Applied Load - Pounds	FF	SC_f	FF	SC_f
20	31	1.55	44 2.	2.20
40	54	1.35	70	1.75
60	81	1.35	88	1.47
80	90	1.13	104	1.30
100	92	0.92	109	1.09
120	107	0.89	111	0.93
140	116	0.83	116	0.83
160	118	0.74	122	0.76

Original Physical Properties - Cure 10 Minutes at 330°F

Modulus at 100%, psi	250	190
Tensile, psi	2160	1950
Elongation, %	440	600
Shore "A" Hardness	63	62

Figure 64

Starting Coefficient of Friction - Evaluation of Experimental Polybutadiene Rubbers

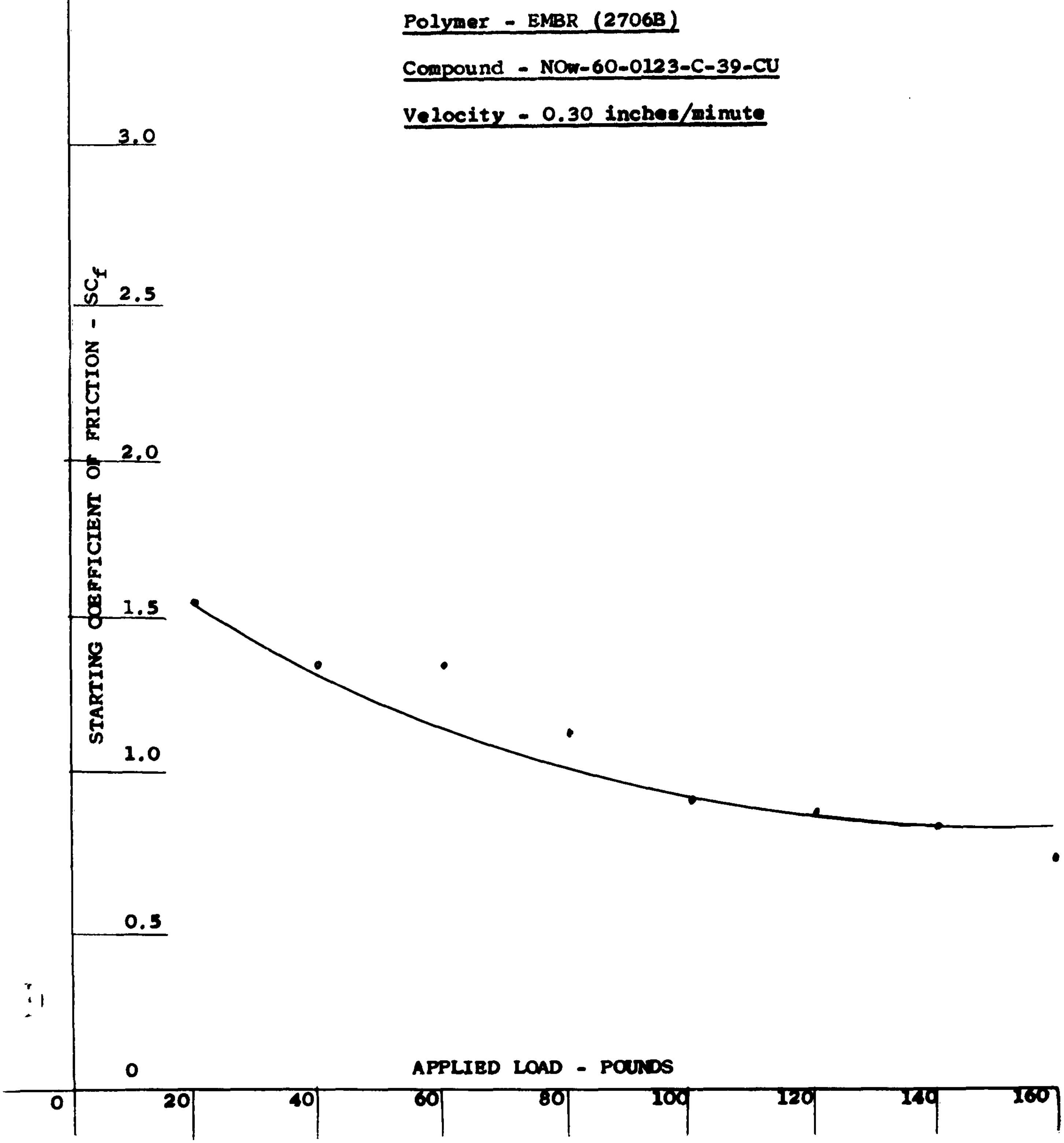
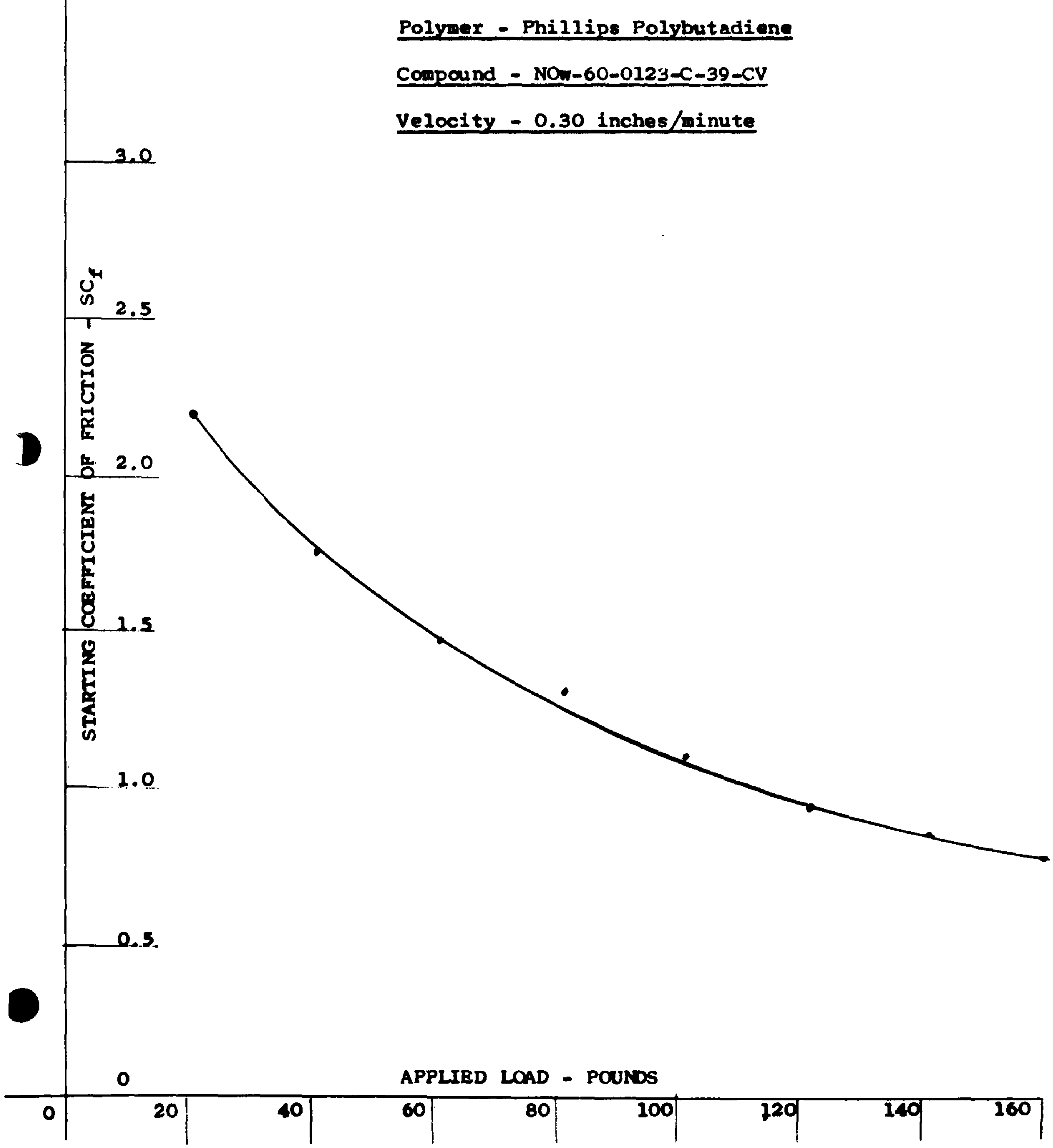


Figure 65

Starting Coefficient of Friction - Evaluation of

Experimental Polybutadiene Rubbers



T A B L E X X I

Starting Coefficient of Friction

Evaluation of Experimental Polyurethane Rubbers

NOw-60-0123-C	52-DZ	52-EA	52-EB	52-EC	52-ED	52-EE
Vibrathane 5003	100.0	-	-	-	-	-
Experimental Vibrathane 5003L	-	100.0	-	-	-	-
" A-531	-	-	100.0	-	-	-
" A-531L	-	-	-	100.0	-	-
" A-528	-	-	-	-	100.0	-
" A-529	-	-	-	-	-	100.0
Stearic Acid	0.25	0.25	0.25	0.25	0.25	0.25
Philblack O Carbon Black	20.00	20.00	20.00	20.00	20.00	20.00
DiCup 40-C	5.00	5.00	5.00	5.00	5.00	5.00
	125.25	125.25	125.25	125.25	125.25	125.25

Cure - 30 minutes at 287°F

Test Velocity - 0.30 inches/minute

Applied Load Pounds	FF	SC_f	FF	SC_f	FF	SC_f	FF	SC_f	FF	SC_f	FF	SC_f
20	48	2.40	52	2.60	60	3.00	55	2.75	44	2.20	52	2.60
40	52	1.30	75	1.97	104	2.60	118	2.95	81	2.03	73	1.83
60	76	1.26	94	1.56	122	2.03	135	2.25	95	1.58	92	1.52
80	104	1.30	123	1.71	175	2.19	175	2.19	128	1.60	118	1.48
100	134	1.34	100	1.00	183	1.83	170	1.70	124	1.24	120	1.20
120	130	1.08	121	1.00	207	1.73	202	1.68	142	1.18	134	1.12
140	143	1.02	122	0.87	198	1.41	210	1.50	160	1.14	142	1.01
160	147	0.92	183	1.43	220	1.38	-	-	235	1.47	153	0.96

Original Physical Properties - Cure 30 minutes at 287°F

Modulus at 100%, psi	470	670	860	820	570	390
Tensile, psi	4400	5050	4230	4420	1750	5500
Elongation, %	400	370	290	310	240	470
Shore "A" Hardness	68	72	77	75	70	68

Figure 66

Starting Coefficient of Friction - Evaluation of

Experimental Polyurethane Rubbers

Polymer - Vibrathane 5003

Compound - NOw-60-0123-C-52-DZ

Velocity - 0.30 inches/minute

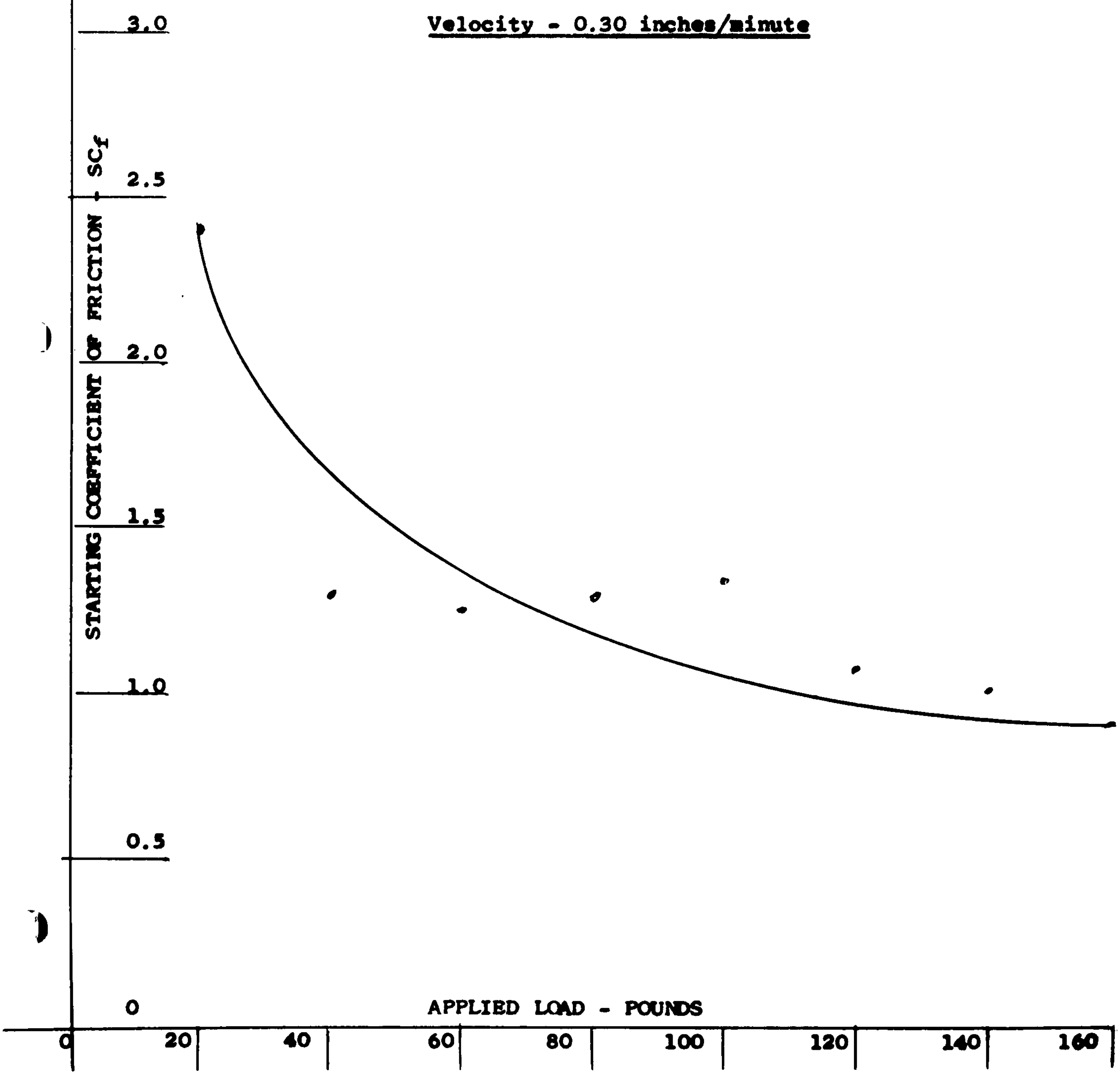


Figure 67

Starting Coefficient of Friction - Evaluation of

Experimental Polyurethane Rubbers

Polymer - Experimental Vibrathane 5003-L

Compound - NOw-60-0123-C-52-EA

Velocity - 0.30 inches/minute

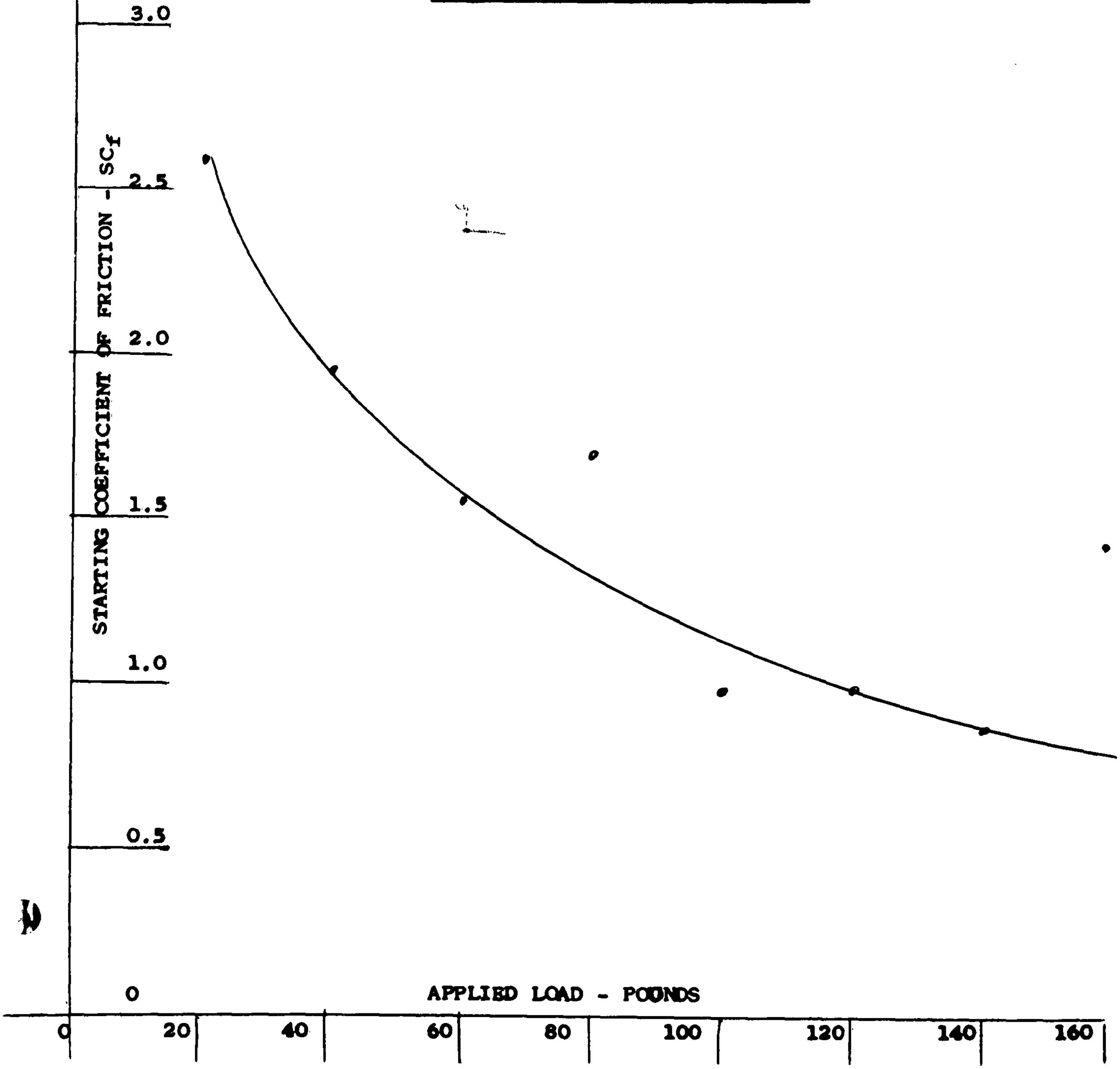


Figure 68

Starting Coefficient of Friction - Evaluation of Experimental Polyurethane Rubbers

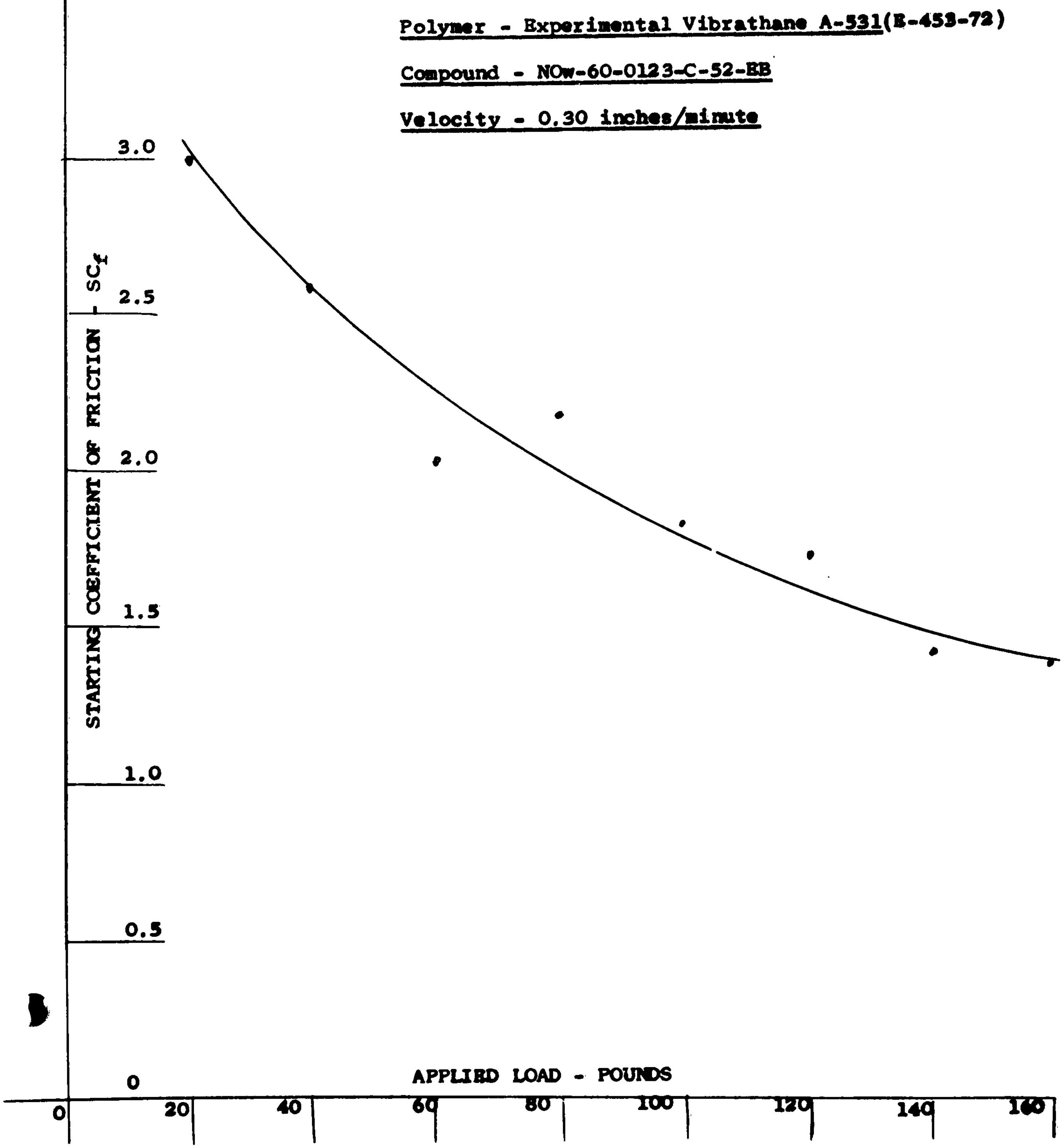


Figure 69

Starting Coefficient of Friction - Evaluation of

Experimental Polyurethane Rubbers

Polymer - Experimental Vibrathane A-531-L(E-453-73)

Compound - NOw-60-0123-C-52-BC

Velocity - 0.30 inches/minute

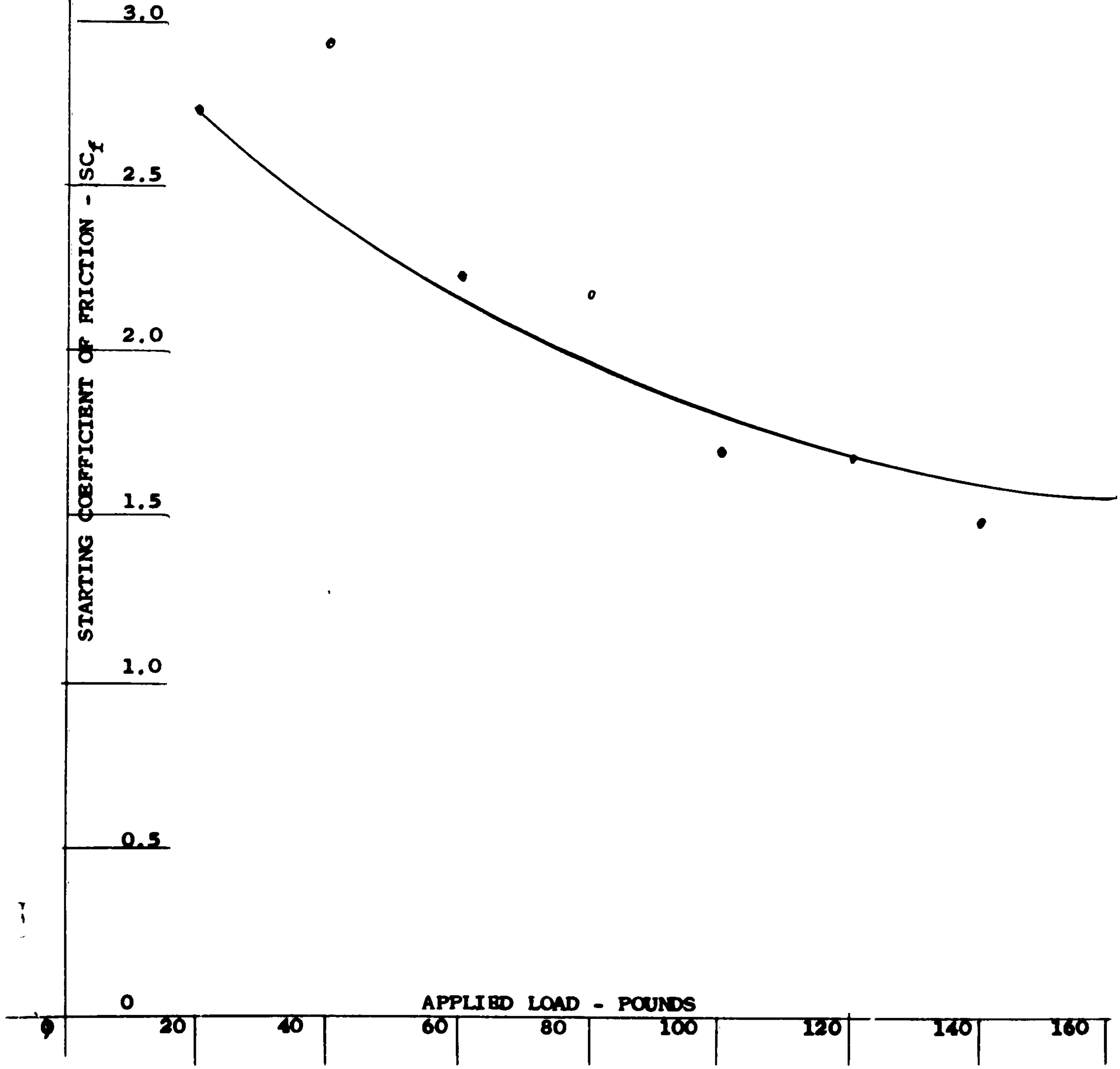


Figure 70

Starting Coefficient of Friction - Evaluation of

Experimental Polyurethane Rubbers

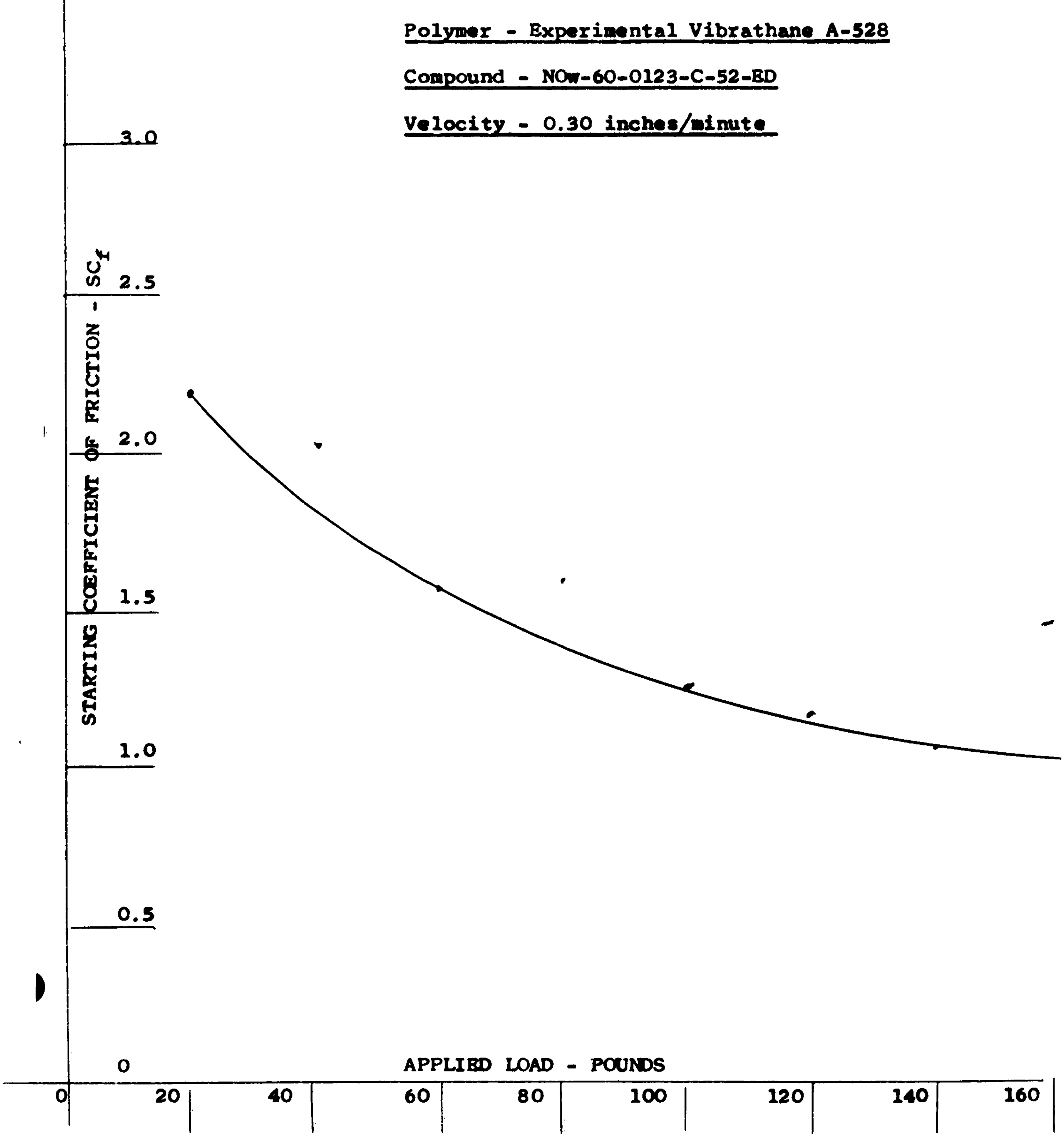


Figure 71

Starting Coefficient of Friction - Evaluation of

Experimental Polyurethane Rubbers

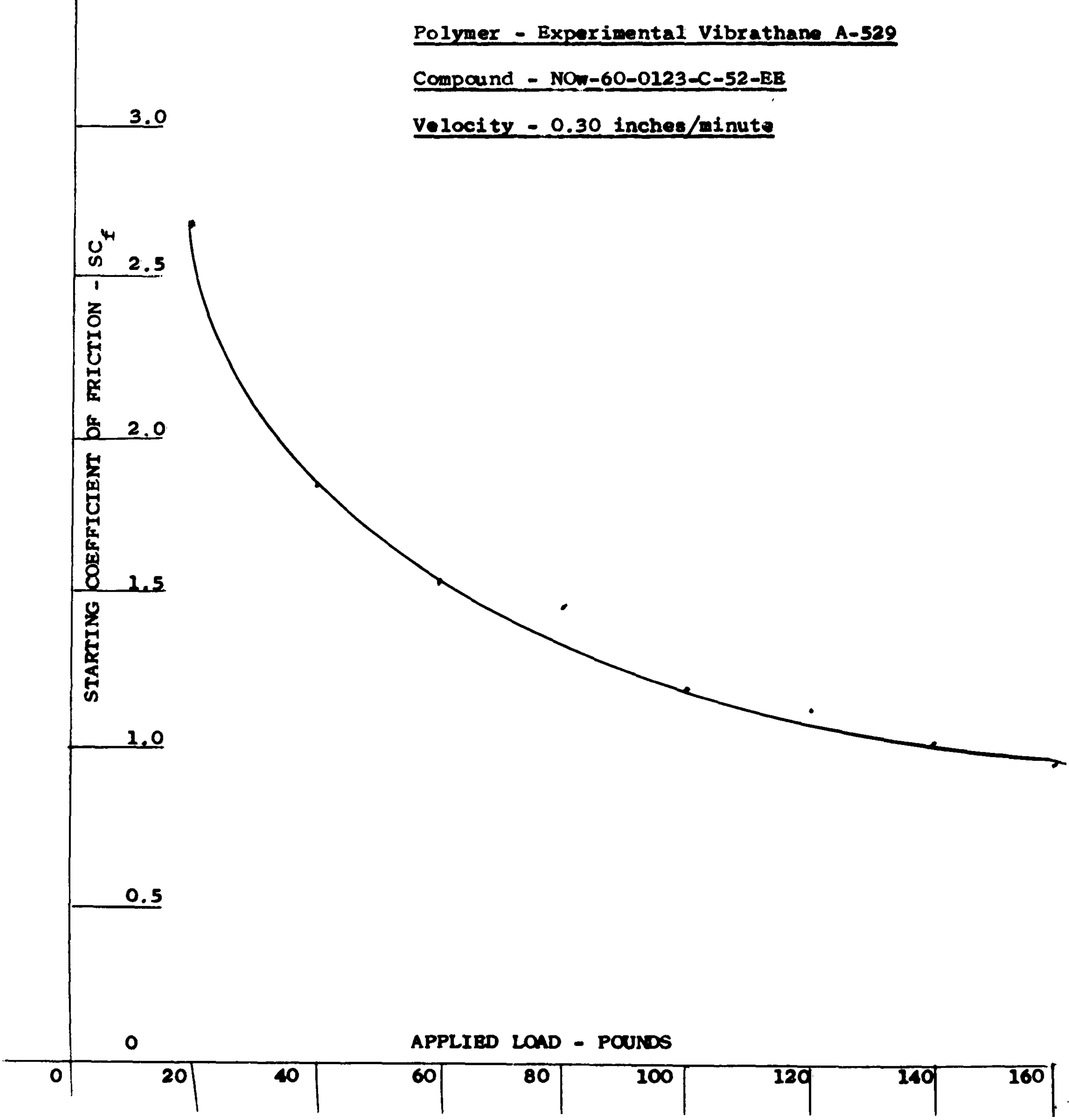


TABLE XXII

Starting Coefficient of Friction

Effect of Contact Time Under Load-Butadiene-Acrylonitrile Rubbers

NOw-60-0123-C	3-C
PARACRIL 18-80	100.0
Zinc Oxide	10.0
AMINOX	2.0
Wyex Carbon Black	25.0
Pelletex Carbon Black	75.0
Paraplex G-25	10.0
Plasticizer SC	7.5
TP-95 Plasticizer	7.5
TUEX	1.5
Tetrone A	1.5
	240.0

Test Specimen Cure - 30 minutes at 310°F

Test Velocity - 0.30 inches/minute

Test Applied Load - 100 Pounds

Contact Time Hours	Frictional Force FF-Pounds	Starting Coefficient of Friction - SC_f
0	86	0.86
2	78	0.78
16	70	0.70
48	74	0.74

TABLE XXIII

Starting Coefficient of Friction

Effect of Contact Time Under Load - Polysulfide Rubber

NOw-60-0123-C	11-AA
Thiokol ST	100.0
Stearic Acid	0.5
G-M-F	1.5
Zinc Oxide	0.5
Philblack A Carbon Black	20.0
Statex B Carbon Black	30.0
	152.5

Test Specimen Cure - 30 minutes at 287°F

Test Velocity - 0.30 inches/minute

Test Applied Load - 100 pounds

Contact Time Hours	Frictional Force FF-Pounds	Starting Coefficient of Friction - SC_f
0	80	0.80
2	90	0.90
16	56	0.56
48	89	0.89

TABLE XXIV

Starting Coefficient of Friction

Effect of Contact Time Under Load

Polysulfide Rubber Compound Containing Graphite

NOw-60-0123-C	22-AZ
Thiokol ST	100.0
Stearic Acid	0.5
G-M-F	1.5
Zinc Oxide	0.5
Philblack A Carbon Black	20.0
Statex B Carbon Black	30.0
Graphite - Rubber Grade	20.0
	172.5

Test Specimen Cure - 30 minutes at 287°F

Test Velocity - 0.30 inches/minute

Test Applied Load - 100 pounds

Contact Time Hours	Frictional Force FF - Pounds	Starting Coefficient of Friction - SC_f
0	40	0.40
2	49	0.49
16	48	0.48
48	54	0.54

TABLE XXV

Starting Coefficient of Friction

Effect of Contact Time Under Load - Fluorocarbon Rubbers

NOw-60-0123-C	17-AJ
Fluorel 2141	100.0
Maglite K Magnesium Oxide	20.0
Thermax MT Carbon Black	15.0
Diak #1	1.0
	136.0

Test Specimen Cure - 30 minutes at 310°F
Air Oven Cure:
1 hour at 200°F
1 hour at 250°F
1 hour at 350°F
24 hours at 400°F

Test Velocity - 0.30 inches/minute

Test Applied Load - 100 pounds

Contact Time Hours	Frictional Force FF - Pounds	Starting Coefficient of Friction - SC_f
0	62	0.62
2	110	1.10
16	102	1.02
48	94	0.94

TABLE XXVI

Starting Coefficient of Friction

Effect of Contact Time Under Load - Fluorocarbon Rubbers

NOw-60-0123-C	6-P
Kel F Elastomer 3700	100.0
Zinc Oxide	10.0
Dyphos	10.0
Thermax MT Carbon Black	15.0
Diak #1	3.0
	138.0

Test Specimen Cure - 30 minutes at 310°F
Air Oven Cure:
16 Hours at 300°F

Test Velocity - 0.30 inches/minute

Test Applied Load - 100 pounds

Contact Time Hours	Frictional Force FF - Pounds	Starting Coefficient of Friction - SC_f
0	58	0.58
2	117	1.17
16	136	1.36
48	114	1.14

TABLE XXVII

Starting Coefficient of Friction

Effect of Humidity, Temperature and Contact Time Under Load

Butadiene-Acrylonitrile Rubber Compound

NOw-60-0123-C	3-C
PARACRIL 18-80	100.0
Zinc Oxide	10.0
AMINOX	2.0
Wyex Carbon Black	25.0
Pelletex Carbon Black	75.0
Paraplex G-25	10.0
Plasticizer SC	7.5
TP-95 Plasticizer	7.5
TUEX	1.5
Tetrone A	1.5
	240.0

Test Specimen Cure - 30 minutes at 310°F

Test Velocity - 0.30 inches/minute

Test Applied Load - 20 pounds

Specimen No.	Test Conditions	Frictional Force FF-Pounds	Starting Coefficient of Friction-SC_f	Remarks
1.	48 hrs. contact time at room temperature and normal room humidity	37	1.85	No effect on test plate
2.	48 Hrs. contact time at 100°F and 100% relative humidity	32	1.60	No effect on test plate
3.	96 Hours contact time at room temperature and normal room humidity	34	1.70	No effect on test plate
4.	96 hrs. contact time at 100°F and 100% relative humidity	47	2.35	Edge corrosion noted at point of contact of test specimens with metal plate

TABLE XXVIII

Starting Coefficient of Friction

Effect of Humidity, Temperature and Contact Time Under Load

Evaluation of a Butadiene-Acrylonitrile Rubber Compound

Treated with Quantum "Slippery" Rubber Process

NOw-60-0123-C 63-FM

PARACRIL 18-80 "O" ring compound (NOw-60-0123-C) shown below treated with Quantum "Slippery" Rubber Process

NOw-60-0123-C	3-C
PARACRIL 18-80	100.0
Zinc Oxide	10.0
AMINOX	2.0
Wyex Carbon Black	25.0
Pelletex Carbon Black	75.0
Paraplex G-25	10.0
Plasticizer SC	7.5
TP-95 Plasticizer	7.5
TUEX	1.5
Tetrone A	1.5
	240.0

Test Specimen Cure - 30 minutes at 310°F
Test Velocity - 0.30 inches/minute
Test Applied Load - 20 pounds

Experiment No.	Test Conditions	Frictional force FF-Pounds	Starting Coefficient of Friction SC_f	Remarks
1. f	0 hrs contact time at 73°F and 50% humidity	4	0.20	Very,very sligh staining noted
2.	96 hours contact time at 100°F and 100% relative humidity	14 plus	0.70 plus	Very bad edge and contact corrosion noted at point of contact of test specimen with metal plate. SC_f value reduced to 0.30 when tested on clean surface of same plate

T A B L E   X X I X

Starting Coefficient of Friction

Effect of Humidity, Temperature and Contact Time Under Load

Evaluation of Teflon Fabric Laminated to

Butadiene-Acrylonitrile Rubber Compound

NOw-60-0123-C 50-DX

"Teflon" woven fabric with one surface napped or brushed. Napped surface laminated and mechanically bonded to compound 3-C shown below.

NOw-60-0123-C	3-C
PARACRIL 18-80	100.0
Zinc Oxide	10.0
AMINOX	2.0
Wyex Carbon Black	25.0
Pelletex Carbon Black	75.0
Paraplex G-25	10.0
Plasticizer SC	7.5
TP-95 Plasticizer	7.5
TUEX	1.5
Tetrone A	1.5
	240.0

Test Specimen Cure - 30 minutes at 310°F
Test Velocity- 0.30 inches/minute
Test Applied Load - 20 pounds

Experiment no.	Test Conditions	Frictional Force FF - Pounds	Starting Coefficient of Friction SC_f	Remarks
1.	0 hours contact time at 73°F and 50% humidity	0.5	0.03	No effect on test plate
2.	96 hours contact time at 100°F and 100% relative humidity	2	0.10	Very,very slight edge corrosion noted at point of contact of test specimen with metal plate. SC_f value reduced to 0.075 when tested on clean surface of same plate

IDENTIFICATION OF COMMERCIAL OR EXPERIMENTAL MATERIALS

USED IN THE COMPOUND FORMULATIONS

Name	Company	General Description
PARACRIL 18-80	Naugatuck Chemical Div. of U.S.Rubber	Low acrylonitrile content butadiene-acrylonitrile copolymer
EPR J-9028-A	Naugatuck Chemical Div. of U. S. Rubber	Experimental stereoregular ethylene propylene copolymer Random configuration
Kel F Elastomer 3700	Minnesota Mining and Manufacturing Co.	Saturated halofluorocarbon copolymer of chlorotrifluoro ethylene and vinylidene fluoride
EPR EP-931	"	Experimental stereoblock ethylene-propylene copolymer planned configuration
EPR J-8745-A	"	"
Philblack O Carbon Black	Phillips Chemical Co.	High Abrasion Furnace Black
DiCup HAF -40	Hercules Powder Co.	Dicumyl peroxide with 60% high abrasion furnace black filler
AMINOX	Naugatuck Chemical Div. of U. S. Rubber	Amine antioxidant for heat and oxygen aging
P-33 Carbon Black	R.T.Vanderbilt Co.	Fine thermal black
TUEX	Naugatuck Chemical Div. of U. S. Rubber	Tetramethyl thiuram disulfide
ETHYL TUEX	"	Tetraethyl thiuram disulfide
Dyphos	National Lead Co.	Dibasic lead phosphite
Philblack A Carbon Black	Phillips Chemical Co.	Fast Extrusion Furnace Black

Name	Company	General Description
DELAC-S	Naugatuck Chemical Div. U. S. Rubber	N-cyclohexyl 2-benzothiazole sulfenamide
Thiokol ST	Thiokol Chemical Corp.	Organic polysulfide rubber
G-M-F	Naugatuck Chemical Div. of U. S. Rubber	p-quinonedioxime
Statex B Carbon Black	Columbian Carbon Co.	Zinc Furnace Black
Wyex Carbon Blk.	J. M. Huber Corp	Easy Processing channel Black
MONEX	Naugatuck Chemical Div. of U. S. Rubber	Tetramethyl thiuram disulfide
Pelletex Carbon Black	G. L. Cabot Corp.	Semi-reinforcing furnace black
Tetrone A	E.I.duPont de Nemours Corp.	Dipentamethylene thiuram tetrasulfide
Paraplex G-25	Rohm and Haas Co.	Polymerized polyester plasticizer
Plasticizer SC	E. F. Drew Co.	Glycol Ester of Vegetable fatty acid
TP-95	Thiokol Chemical	Monomeric Diester
Cis 4 Polybutadiene	U. S. Rubber Co.	Polybutadiene polymer
FLEXZONE 3-C	Naugatuck Chemical Div. of U. S. Rubber	Antiozonant, N-isopropyl-N'-phenyl-p-phenylene diamine
Philrich #5	Phillips Chemical	Petroleum oil plasticizer
NAUGAPOL 1015	Naugatuck Chemical Div. of U. S. Rubber	Butadiene-styrene copolymer-very low styrene content
Rosin 731-D	Hercules Powder Co.	Wood Rosin
Vibrathane 5003	Naugatuck Chemical Div. of U. S. Rubber	Millable polyurethane rubber

Name	Company	General Description
DiCup 40-C	Hercules Powder Co.	Dicumyl peroxide with 60% inert calcium carbonate filler
Fluorel 2141	Minnesota Mining and Manufacturing Co.	Copolymer of vinylidene fluoride and hexafluoro
Thermax Carbon Blk.	R. T. Vanderbilt	Medium thermal black
Diak #1	E.I.duPont de Nemours Co.	Hexamethylene diamine carbamate
Graphite	Asbury Graphite Mills	Allotropic form of carbon
Dow Corning #3 Compound	Dow Corning	Silicone grease
Viton A	E.I.duPont de Nemours Company	Copolymer of vinylidene fluoride and hexafluoro propylene
Teflon Floc	"	Tetrafluoroethylene fiber
Teflon 7 Resin	"	Tetrafluoroethylene resin
Kel F Resin 300	Minnesota Mining & Mfg. Co.	Polytrifluorochloro ethylene resin
Kel F Wax 200	"	Polytrifluorochloro ethylene heavy wax
Kel F Oil 10	"	polytrifluorochloro ethylene heavy oil.
Vydax A	E.I.duPont de Nemours	Low molecular weight telomer of TFE in Freon TF solvent
TLT-111	"	Experimental low molecular weight telomer of TFE
Flexament PCM 1278	Swift & Co.	Extreme pressure lubricant
Silastic LS-53	Dow Corning	fluorosilicone rubber
Silastic 82	"	Silicone rubber

Name	Company	General Description
Experimental EMBR 2706B	Dow Corning	Emulsion polymerized poly-butadiene - experimentally prepared
Experimental Vibrathane 5003L	Naugatuck Chemical Div. of U. S. Rubber	Solid polyurethane chain extended with diamine containing 1% molybdenum di-sulfide and 1% silicone oil added during reaction
Experimental Vibrathane A-528	"	Solid polyurethane chain extended with a diol
Experimental Vibrathane A-529	"	Solid polyurethane chain extended with a diol- more rigid than A-528
Experimental Vibrathane A-531	"	Solid polyurethane based on toluidine diisocyanate and chain extended with a diamine
Experimental Vibrathane A-531L	"	Same as A-531 except 1% molybdenum disulfide and silicone oil added during reaction.